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**DEVELOPMENT OF A MOLTEN CARBONATE PROCESS  
FOR REMOVAL OF SULFUR DIOXIDE  
FROM POWER PLANT STACK GASES**

**PROGRESS REPORT NUMBER 2  
PART VI. SMALL PILOT PLANT AND COMPONENT  
TEST LOOP DESIGN**

**April 1, 1968 to October 27, 1968**

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**North American Rockwell**

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Canoga Park, California 91304

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The work upon which this publication is based was performed by Atomics International, A Division of North American Rockwell Corporation, Canoga Park, California, pursuant to Contract No. PH 86-67-128 with the U. S. Public Health Service, Department of Health, Education, and Welfare. Patents covering the basic process have been issued to North American Rockwell Corporation.



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## I. SUMMARY

→ The development program for the Molten Carbonate Process involves the design, construction and operation of two test systems, a Small Pilot Plant (SSP) and a Component Test Loop (CTL). The Small Pilot Plant will be used to test and evaluate the performance of the integrated process on a continuous basis under realistic plant operating conditions. The Component Test Loop will be used to establish the performance and reliability of equipment components of a size comparable to those of a demonstration unit. <sup>The</sup> This report presents the conceptual designs and cost estimates for designing and constructing the two test systems. (1)

## II. INTRODUCTION

The objectives of this report are:

- a) To present a description of the conceptual designs of these test systems,
- b) To explain the necessity for design verification and performance testing, and
- c) To present a budgetary cost estimate for constructing the test systems.



A. SMALL PILOT PLANT (SPP)

This system will be operated to test and evaluate the performance of the chemical reactors and to demonstrate the process feasibility on an integrated basis under realistic plant operating conditions and on a continuous basis. Secondary objectives will be to study the effects of operational variation on plant performance and of trace impurities on process chemistry, also on a continuous basis. The results of these tests will be utilized to develop specifications and operating criteria for a demonstration plant.

B. COMPONENT TEST LOOP (CTL)

This system will be operated to test mechanical components of a size comparable to those anticipated for the large pilot plant (a molten carbonate plant integrated into a 60-100 Mwe coal fired unit). The principal purpose of the Component Test Loop is to test equipment designed and supplied by manufacturers wherever possible, and not for the purpose of developing new equipment concepts. Prime objectives are the demonstration of component performance, reliability and useful life under simulated plant operating conditions, and the development of final procurement specifications from the operating data. Components to be tested include pumps, valves, flow measurement devices, heat exchangers, fly ash removal devices, and process instrumentation. These components cannot be evaluated properly in the Small Pilot Plant because of the nature of the test program, which will undoubtedly involve intermittent operation and periodic replacement of major components. Furthermore, existing equipment manufacturer's test facilities are not capable of testing the components at design conditions with the process fluids of interest.



### III. DESCRIPTION OF TEST FACILITY

#### A. SMALL PILOT PLANT

The basic feasibility of the molten carbonate process has been demonstrated experimentally. However, the parametric effects of the process variables have not yet been sufficiently well determined to develop fixed designs for all components of the Small Pilot Plant. Therefore, during the course of preparing the conceptual design of the Small Pilot Plant, it was necessary to select process conditions based upon the best available information. Additional process development work will undoubtedly indicate the wisdom of revising some of these conditions, and consequently modifying the process during subsequent detailed design efforts.

The following bases were utilized in designing the equipment:

- |                |                                                                                                                                                                                                           |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Absorber       | - Spray column with gas velocity limited to 25 ft/sec.<br>Operating temperature, 850°F. Gas input, 1200 SCFM                                                                                              |
| Fly Ash Filter | - Stainless steel cartridge type filters, sized for an operating cycle with maximum of one week operation between cake removal periods. Operating temperature, 850°F.                                     |
| In-Line Heater | - Natural gas fired heater designed to continuously heat the molten salt from 850 to 1100°F prior to the reduction step. (Provisions will be made to utilize the same heater in the Component Test Loop). |
| Reducer        | - Sieve tray column or stirred tank reactors.<br>Operating temperature 1050-1100°F. Provision will be made for recycle. Size will be sufficient to provide scaleup information.                           |

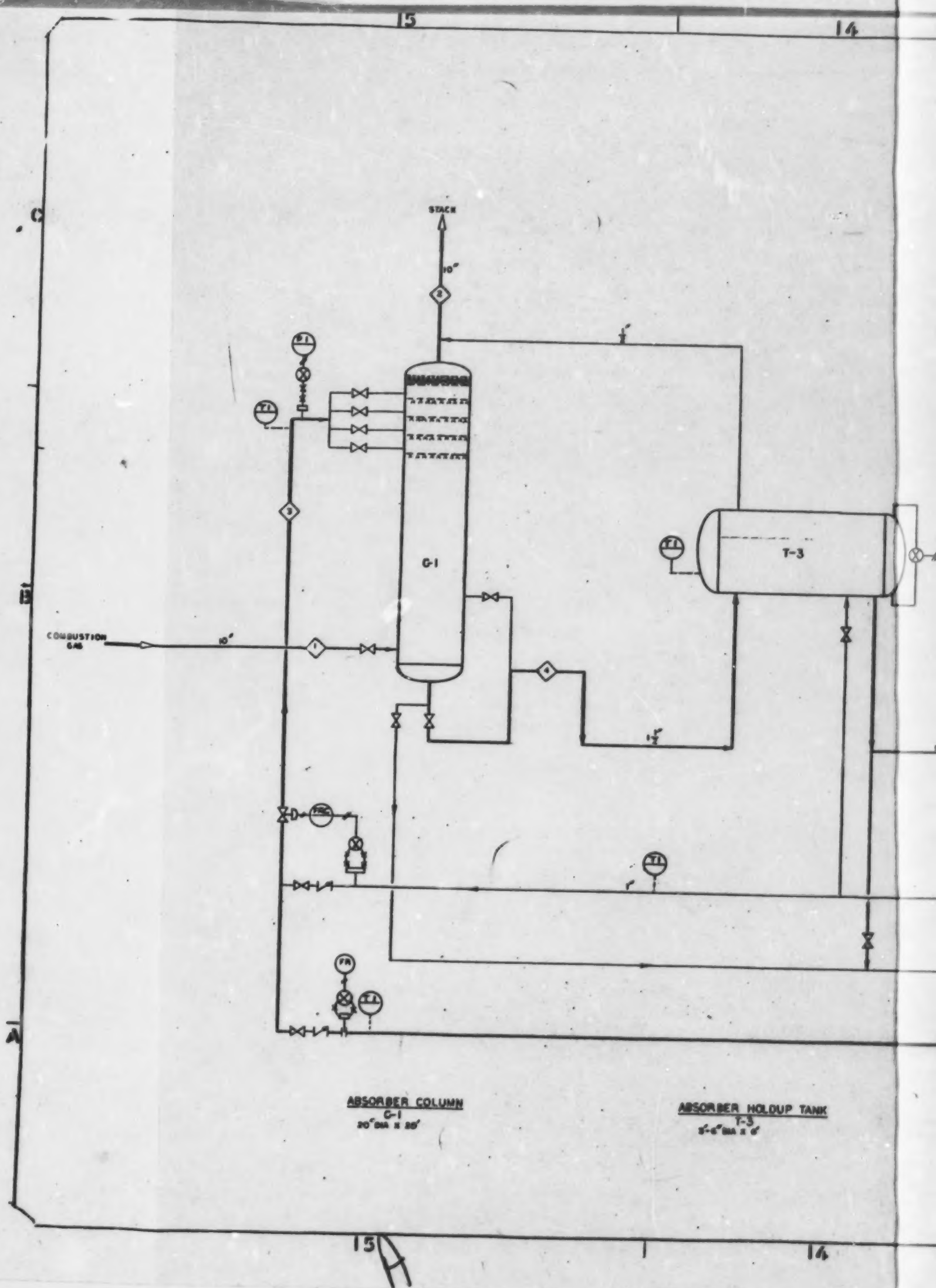


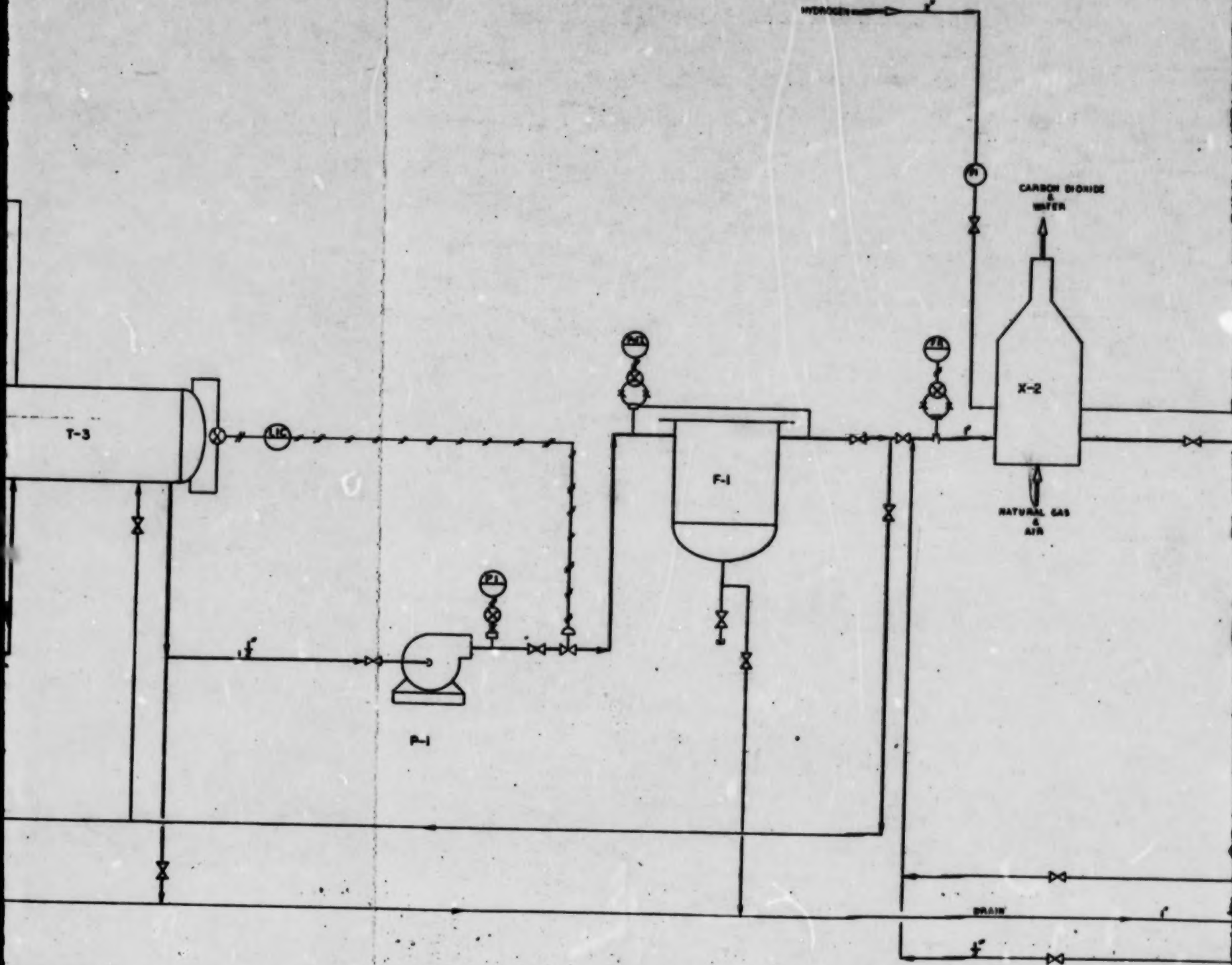
- Reducing Gas - Pure hydrogen or hydrogen-rich gas containing some carbon monoxide from a steam-natural gas reformer.
- In-Line Cooler - Heat exchanger to reduce temperature from 1050-1100°F to 800-850°F prior to regenerator.
- Regenerator - Sieve tray column or stirred tank reactors. Operating temperature 800-850°F. Provision will be made for recycle. Size will be sufficient to provide scaleup information.
- Regeneration Gas - Carbon dioxide and steam.
- Catalyst Filter - Stainless steel cartridge type filter. Operating temperature, 850°F.
- Pumps - Vertical, free surface pumps.
- Materials - Absorber, filters, regenerator - type 347 stainless steel; in-line heater, in-line cooler, reducer, special high temperature alloy such as Hastelloy G.
- Location - High Bay area of SRE facility at Atomics International's nuclear field laboratory.

This ensuing discussion presents a system description of the Small Pilot Plant based upon the conceptual design effort. It must be re-emphasized that the specific sizes, quantities, and type of reactors referred to are preliminary and will be re-evaluated during the final design effort.

1. Base Case - Sieve Tray Columns for Reducer and Regenerator

Figure 1 is a Process and Instrumentation (P&I) drawing of the proposed system. It contains data on component sizes and energy requirements. Table I presents data on material balances around the major components for one set of operating conditions.





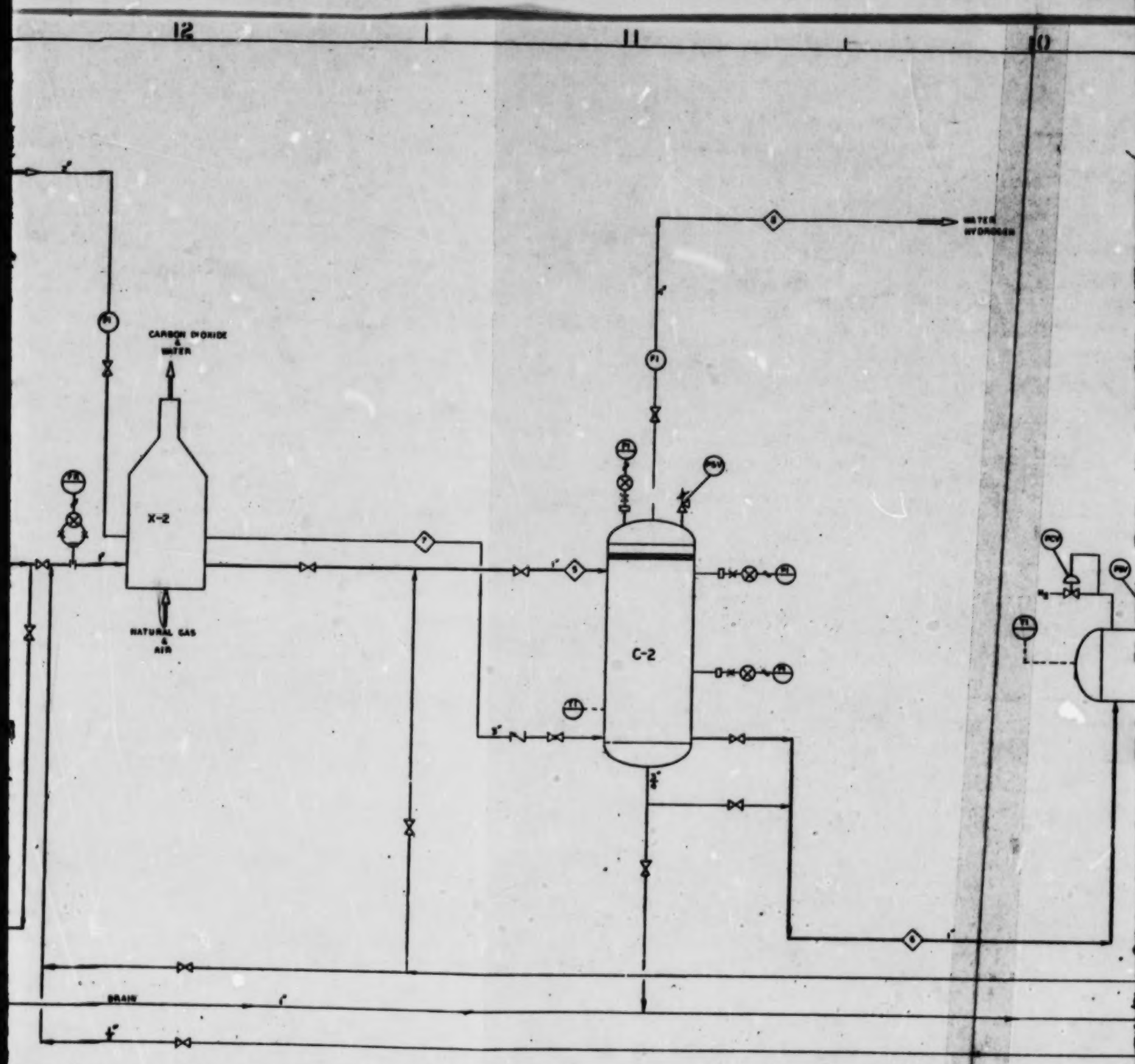
WATER HOLDUP TANK  
T-3  
14 x 6'

ABSORBER PUMP  
P-1  
CAPACITY 8 GPM  
HEAD 170 PSI  
HP 7 1/2

FLY ASH FILTER  
F-1  
RATING 2 MICRONS

HEATER  
X-2  
DUTY: CARBONATE 850,000 BTU/HR.  
HYDROGEN 900,000 BTU/HR.

13 B



**HEATER**  
 X-2  
 DUTY: CARBONATE 950,000 BTU/HR  
 HYDROGEN 900,000 BTU/HR

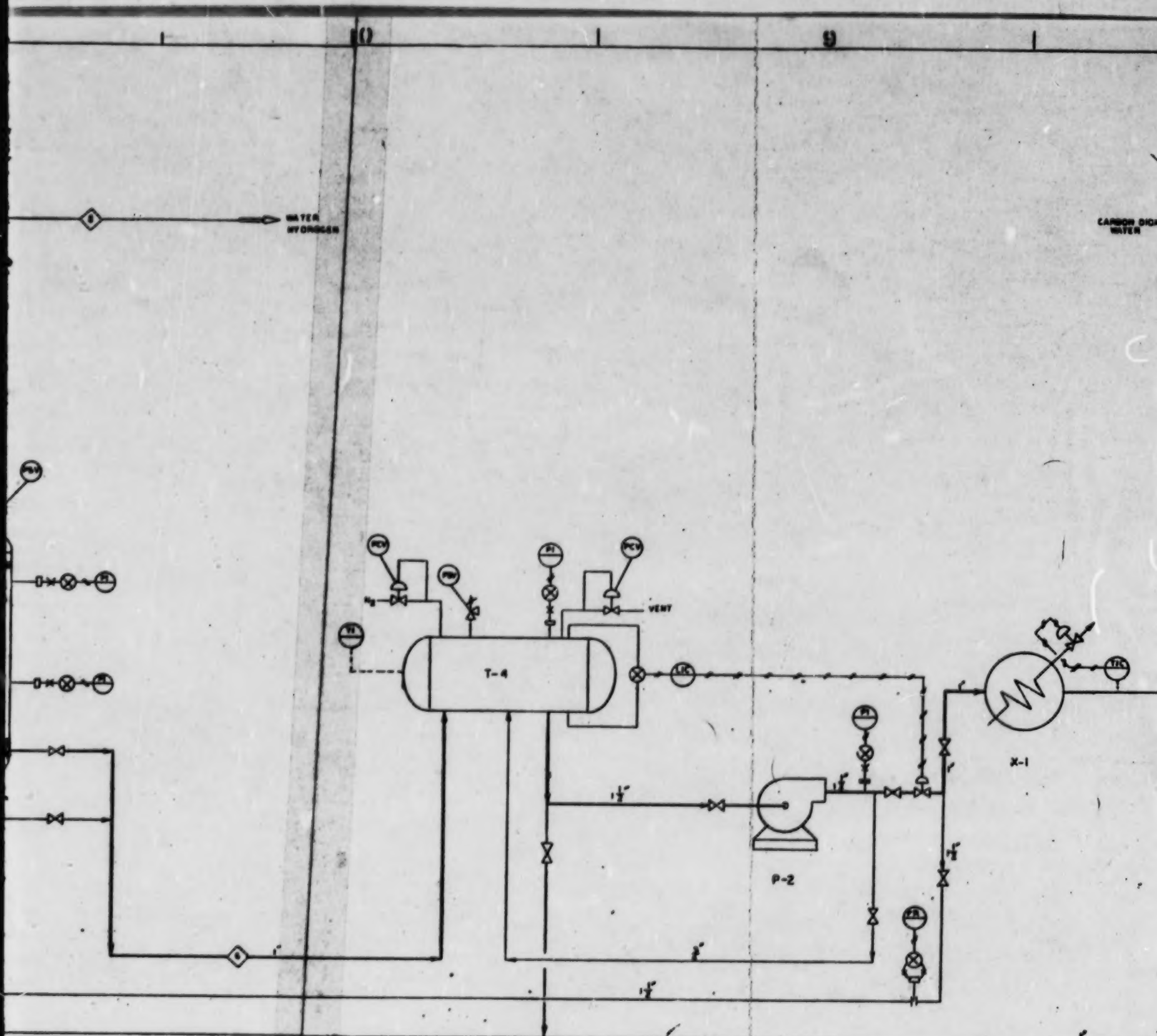
**REDUCER COLUMN**  
 C-2  
 3" DIA X 18'

**REDUCER HO**  
 T-4  
 6" DIA X 10'

12

11

10



**REDUCER HOLDUP TANK**

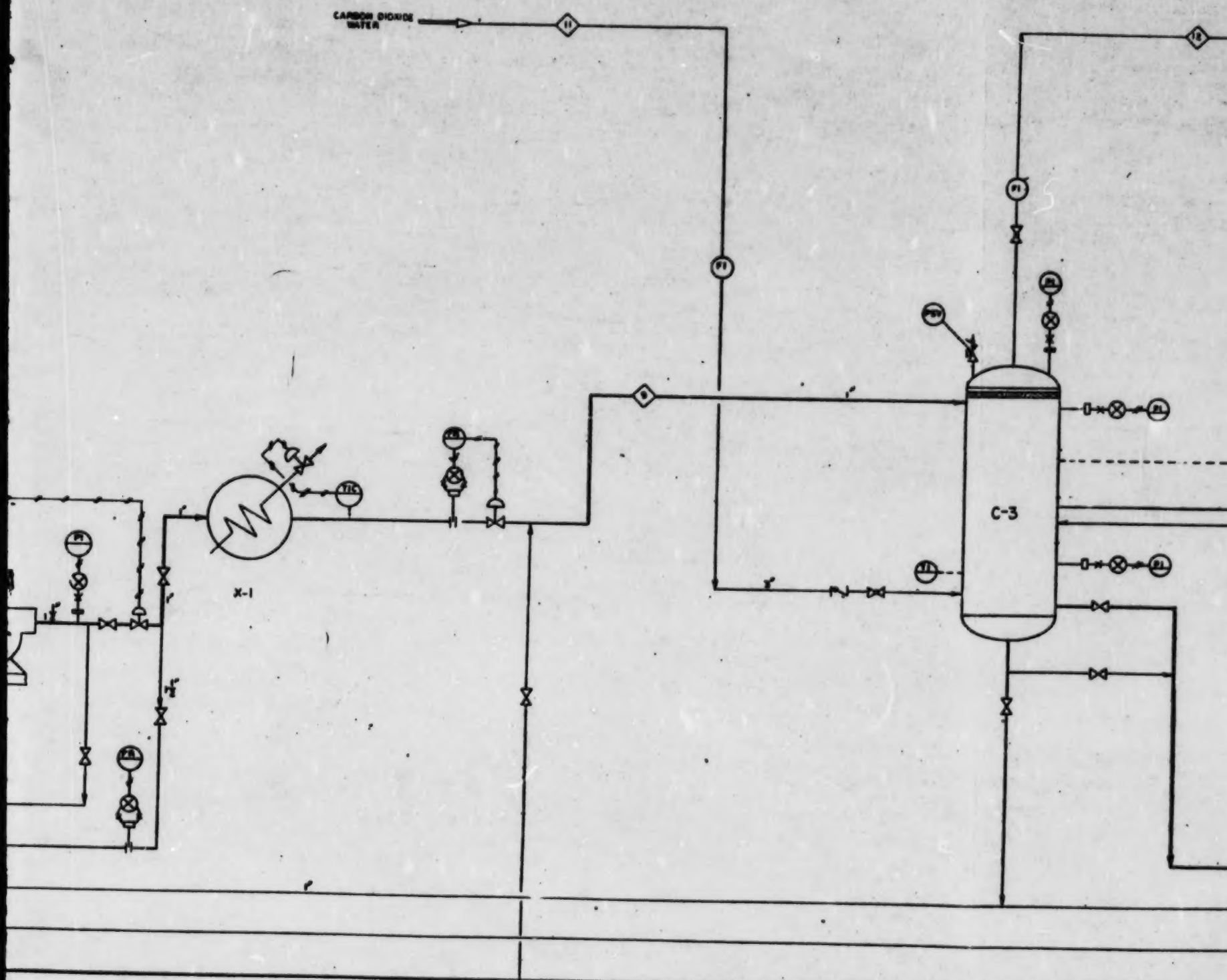
T-4  
6' DIA X 10'

**REDUCER PUMP**

P-2  
CAPACITY: 30 GPM  
HEAD: 90 PSI  
NP 1 9

**REGENERATOR COOLER**

X-1  
DUTY 750,000 BTU/HR

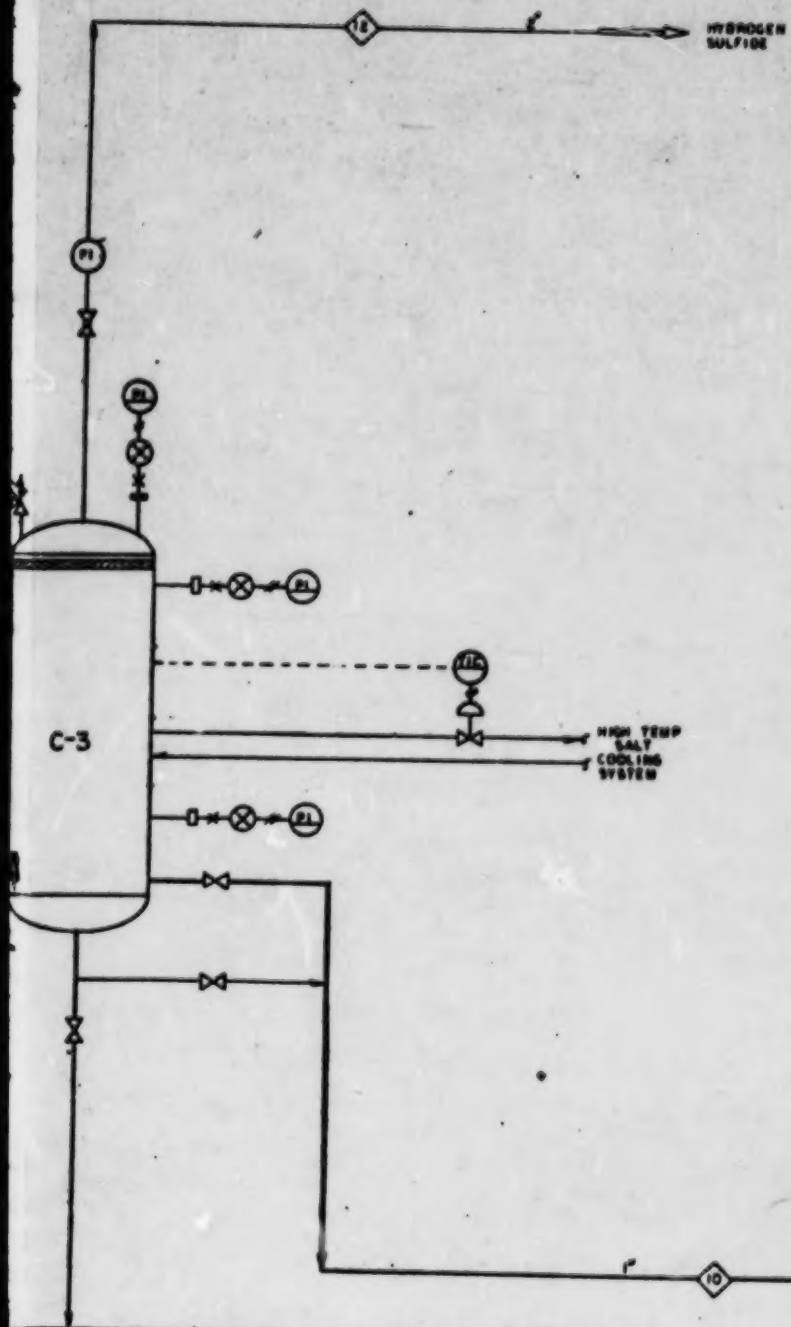


UMP  
GPM  
PSI

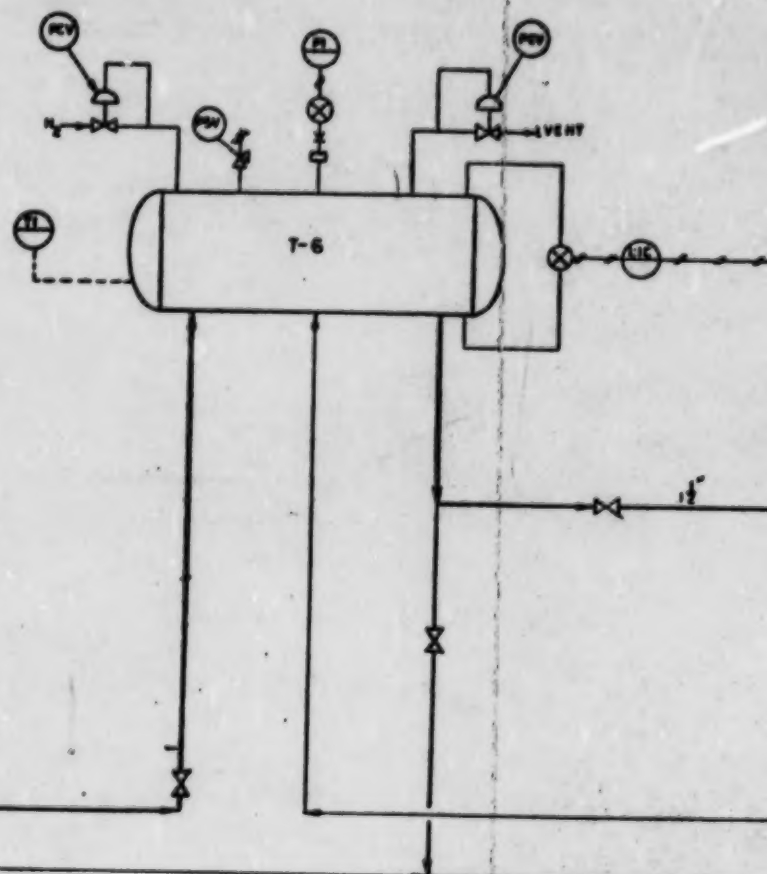
REGENERATOR COOLER  
X-1  
DUTY 750,000 BTU/Hr

REGENERATOR COLUMN  
C-3  
3" DIA x 12'

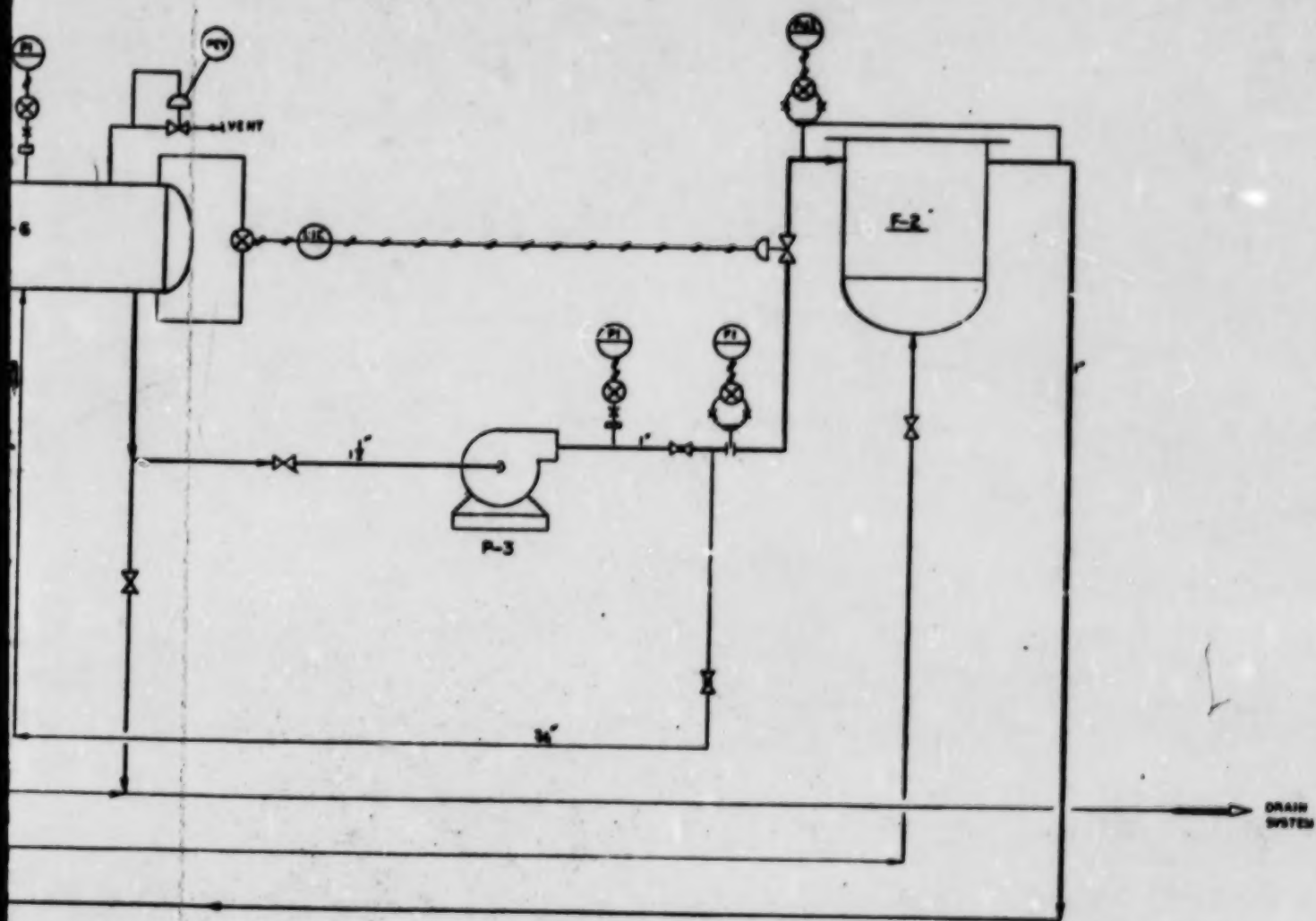
~



GENERATOR COLUMN  
C-3  
8' DIA X 12'



REGENERATOR HOLDUP TANK  
T-6  
8' DIA X 8'



UP TANK

REGENERATOR PUMP  
P-3  
CAPACITY: 5 GPM  
HEAD: 60 PSI  
HP: 5

CATALYST FILTER  
F-2  
RATING: 5 MICRONS

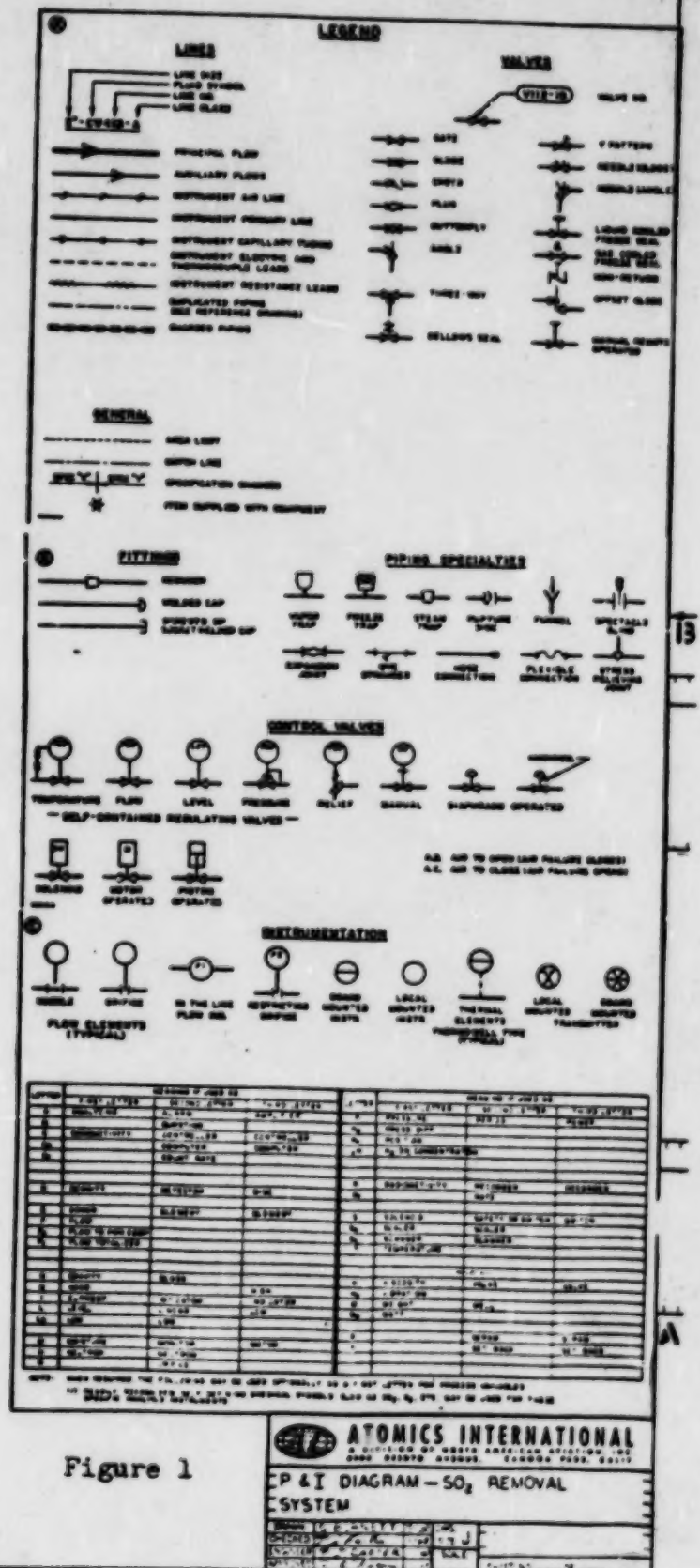


Figure 1

TABLE 1  
MATERIAL BALANCE - SO<sub>2</sub> REMOVAL SYSTEM

| Process Material         | Absorber |         |         |         | Reducer   |           |           | Regenerator |         |         |         |         |
|--------------------------|----------|---------|---------|---------|-----------|-----------|-----------|-------------|---------|---------|---------|---------|
|                          | 1*       | 2       | 3       | 4       | 5         | 6         | 7         | 8           | 9       | 10      | 11      | 12      |
| Metal Carbonate (lb/hr)  |          |         | 4520    | 4560    | 12,500    | 12,500    |           |             | 3800    | 5300    |         |         |
| Metal Sulfate (lb/hr)    |          |         | 950     | 980     | 1,735     |           |           |             |         |         |         |         |
| Metal Sulfite (lb/hr)    |          |         | 1430    | 1470    |           |           |           |             |         |         |         |         |
| Metal Sulfide (lb/hr)    |          |         |         |         | 2,770     | 3,690     |           |             | 1130    | 50      |         |         |
| Iron (lb/hr)             |          |         |         |         | 400       | 400       |           |             | 150     | 150     |         |         |
| Fly Ash (lb/hr)          | 0.4      | -       | -       | 0.4     |           |           |           |             |         |         |         |         |
| Oxygen (lb/hr)           | 290      | 290     |         |         |           |           |           |             |         |         |         |         |
| Hydrogen (lb/hr)         |          |         |         |         |           |           | 127       | 25          |         |         |         |         |
| Carbon Dioxide (lb/hr)   | 1100     | 1100    |         |         |           |           |           |             |         |         | 825     | 165     |
| Water (lb/hr)            | 320      | 320     |         |         |           |           |           | 920         |         |         | 335     | 65      |
| Hydrogen Sulfide (lb/hr) | 385      | -       |         |         |           |           |           |             |         |         |         | 510     |
| Sulfur Dioxide (lb/hr)   | 4130     | 4130    |         |         |           |           |           |             |         |         |         |         |
| Nitrogen (lb/hr)         |          |         |         |         |           |           |           |             |         |         |         |         |
| Total Flow (lb/hr)       | 5880     | 5840    | 7000    | 7010    | 17,405    | 16,590    | 127       | 945         | 5080    | 5500    | 1160    | 740     |
| Temperature (°F)         | 800-850  | 800-850 | 800-850 | 800-850 | 1050-1100 | 1050-1100 | 1050-1100 | 1050-1100   | 800-850 | 800-950 | 800-850 | 800-850 |
| Pressure (psig)          | Atm      | Atm     | 20      | Atm     | 60        | 60        | 60        | 60          | 60      | 60      | 60      | 60      |

\*Numbers correspond to numbered locations in Figure 1



The gas to be treated is removed from a flue gas generator at 800-850°F (although the method of flue gas generation is not shown, it is assumed that a pulverized coal furnace is used). The gas then passes through a high temperature precipitator, which removes approximately 99% of the fly ash. A by-pass around the precipitator is installed to facilitate studies of the effects of higher fly ash concentration on absorber and fly ash removal device performance. The gas stream then passed through an absorber where it is contacted with a molten carbonate spray at 800-850°F. The absorber is a 20-in. diameter unit with a linear gas velocity of 25 ft/sec. The scrubbing process removes more than 95% of the sulfur oxides and the remaining fly ash from the gas stream. The clean gas stream is then exhausted to the atmosphere through a stack. The process melt is pumped from the absorber through a fly ash removal device to remove the fly ash, through an in-line heater to raise the temperature from 800-850°F to 1050-1100°F, and into the reducer stage. The sulfate in the process melt is reduced with a hydrogen-rich gas to form sulfide. The process stream is removed from the reducer through an in-line cooler to reduce the temperature from 1050-1100°F to 800-850°F, and into the regeneration stage where it is contacted with a mixture of carbon dioxide and steam to form hydrogen sulfide and carbonate. The hydrogen sulfide is flared to the atmosphere and the carbonate is recycled to the absorber.

The equipment requirements consist of:

- a) Flue gas source\*
- b) Absorption Tower

---

\* If a pulverized coal burning furnace is utilized, an electrostatic precipitator must be installed.



- c) Fly ash removal device
- d) In-line heater
- e) Reducer
- f) In-line cooler
- g) Regenerator
- h) Catalyst filter
- i) Molten salt pumps
- j) Miscellaneous tanks

a. Flue Gas Source (Not Shown in Fig. 1)

The flue gas is generated by a pulverized coal-burning furnace and is passed through a high temperature electrostatic precipitator where approximately 99% of the fly ash is removed. A precipitator by-pass line is provided to facilitate investigation of the effects of fly ash concentration on the process. Alternative methods of generating the flue gases have been investigated, e.g., utilizing an oil or gas burner with sulfur injection. Provision is made to inject additional sulfur dioxide to the flue gas in order to conduct experimentation to determine limiting conditions in reducers and regenerators of sufficient size to provide scaleup information.

b. Absorber

The hot flue gases (800-850°F) are contacted with a liquid spray of molten carbonate in the absorber column (C-1). The absorber is a 20-inch diameter x 20-ft high unit fabricated from type 347 stainless steel, and is sized to give a linear gas velocity of 25 ft/sec. Molten carbonate is pumped into the column through spray headers located throughout the column. An excess of carbonate melt is supplied to the column. The scrubbing process



removes more than 95% of the sulfur oxides and all the remaining fly ash from the gases. The scrubbed gases are then passed through a mist separation device and are exhausted to the atmosphere.

c. Fly Ash Removal Device

A fly ash removal device (F-1) is installed in the liquid stream from the absorber. As currently conceived, this device will be a bank of stainless steel cartridge type filters which will be back washed as required to remove the filter cake. Other methods of continuous removal are being investigated, including continuous centrifugation. The filter cake recovered can be used in separate tests to study methods for recovering the carbonate it contains.

d. In-Line Heater

The process stream to the reducer will be heated from 850 to 1100°F by a natural-gas-fired, in-line heater (X-2) and fed to the reducer. The sulfite in the process stream will disproportionate to sulfate and sulfide in the heater. In addition, the in-line heater will be used to heat the reduction gas to the reactor temperature.

e. Reducer

The process stream, containing sulfide and sulfate, flows from the heater into the reduction stage where it is contacted with a hydrogen-rich gas stream in a countercurrent sieve-tray column (C-2). The liquid enters the top of the column where it mixes with the catalyst-rich stream from the catalyst filter and flows downward over sieve plates in series. The hydrogen-rich gas enters at the bottom of the column and flows upward through holes in the plates and then bubbles through the liquid held up on the plate. It is



this liquid-gas interaction that allows the sulfate to react with the hydrogen to form sulfide. The sulfide is carried along with the carbonate and unreacted sulfate onto the next plate, where additional conversion of sulfate to sulfide is accomplished. This process continues on down the column until all of the sulfate is converted to sulfide. The reduction column is 3 ft in diameter and 18 ft high and contains 15 sieve trays spaced 1-ft apart. It is planned to use Hastelloy G as the construction material. Provisions are made to study the effect of recycle on reducer performance. Plant analysis indicates that the overall process cost can be materially reduced when carbon reduction is utilized. It should therefore be recognized that although the above design is based upon the use of hydrogen, it may be modified to enable the use of carbon as the reducing agent.

f. In-Line Cooler

An in-line cooler (X-1) is installed in the process stream from the reducer to reduce the temperature of the reducer effluent from 1100°F to 850°F prior to the regeneration step. Heat is transferred in an auxiliary cooling system by a lower melting point heat transfer salt. In a commercial unit, an economizer would be used in the process streams around the reducer to conserve energy. However, an economizer was not incorporated in the Small Pilot Plant because it would reduce testing flexibility.

g. Regenerator

The process stream from the in-line cooler is contacted with carbon dioxide and steam in another countercurrent sieve-tray column (C-3). This regeneration column is 2-ft in diameter and 12-ft high and contains 10 sieve trays spaced 1-ft apart. This column will be constructed of type 347



stainless steel. The liquid-gas contact results in the formation of hydrogen sulfide and carbonate. The hydrogen sulfide evolves from the liquid and is carried out of the column with the unreacted carbon dioxide and steam. The regenerated carbonate is pumped from the column through an iron catalyst filter and returned to the absorber, completing the cycle. Because the regeneration process is exothermic, the heat of formation must be removed to maintain a constant reaction temperature. This heat is transferred to the auxiliary cooling system, by cooling coils on each plate. Provisions are made to study the effect of recycle on regenerator performance.

#### h. Catalyst Filter

A stainless steel cartridge-type filter (F-2) is installed in the carbonate return line to the absorber column, to remove the iron catalyst from the regenerated melt. This prevents the loss of the catalyst in the fly ash filter. The filtered catalyst is returned to the reducer column, by backwashing. Continuous removal methods are also being investigated.

#### i. Tankage

A holdup tank is installed at the outlet of each column (Tanks T-3, 4 and 6). The tanks provide a liquid surge volume, and enable each column to operate independently of the other portions of the system. Any gas entrained with the liquid leaving the column is also removed in the tank. The holdup tanks also provide capacity for draining the columns, filters, heat exchangers, pumps and piping.

#### j. Pumps

Vertical, free-surface pumps are installed to pump the molten salts into the absorber, reducer and regenerator columns. Three pumps are used



to provide flexibility of operating throughput and pressure. The throughput and pressure in each column may be varied widely and independently of the conditions in the other columns. The requirements and hydraulic conditions of the pumps are similar. Thus, all three pumps will be the same except for modifications to the impeller. Regulation of the flow will be done with control valves located in the pump discharge.

k. Auxiliary Cooling Circuit

A closed-loop cooling circuit (not shown in Figure 1) is provided to remove heat from the carbonate system at high temperatures. The cooling circuit consists of a circulation pump, a surge tank and a forced convection air-cooled heat exchanger. The circulating fluid in the cooling circuit is a high temperature heat transfer salt. The fluid is circulated at a high rate to all locations where high temperature controlled cooling is required. The salt flow rate to the component being cooled is controlled to any desired value. Heat is rejected from the salt through a forced convection air cooled heat exchanger to maintain a constant salt temperature.

l. Gas Supply

Nitrogen is used as a cover gas in the molten carbonate and auxiliary cooling systems. A nitrogen atmosphere is maintained over both the reducer holdup tank and the regenerator holdup tank to exclude air. Nitrogen also is available to displace the molten carbonate when draining other vessels and piping. Nitrogen could also be used to blow the molten carbonate from the low points into the holdup tanks. The nitrogen will be supplied from cylinders manifolded through a pressure reducing valve to a 125 psig nitrogen supply header.



Hydrogen gas is used to reduce the sulfates to sulfides in the reduction step. Hydrogen will either be purchased, stored in tanks or tank trucks and delivered to the reducer column as a gas at 125 psig, or else generated with a packed-unit natural gas reformer. If hydrogen is purchased, provision would be made to add carbon monoxide, to determine the reaction rate of steam reformed natural gas.

Carbon dioxide is used in the regeneration step along with steam to convert the sulfide back to carbonate and to release the sulfur as hydrogen sulfide. Carbon dioxide is stored as a liquid in a tank at 150 psi. Gas is withdrawn from the tank, passes through a pressure reducing valve, and is distributed at 125 psi.

Steam used in the regeneration step is supplied by a small boiler. Tap water is supplied to the boiler and converted to steam by burning natural gas. The 12 hp boiler produces saturated steam to 150 psig.

m. Instrumentation

Instrumentation is provided to monitor the system operation and equipment performance. Instruments to obtain experimental data are installed, as required. Temperature, pressure and flows are measured throughout the system to enable energy and material balances to be made around the absorber, reducer and regenerator. Pressure drop across the filters and pumps is measured. Temperature is measured with chromelalumel thermocouples placed in piping thermowells. NaK-filled dP cells are utilized for absolute pressure and flow determination. Automatic valves are used in control loops to regulate flow, liquid level, and temperature. Pneumatic operators are installed on these valves.



The various gas streams will be analyzed by the use of suitably-prepared gas chromatographs. Provisions will also be made to collect liquid samples for analysis.

n. Preheat

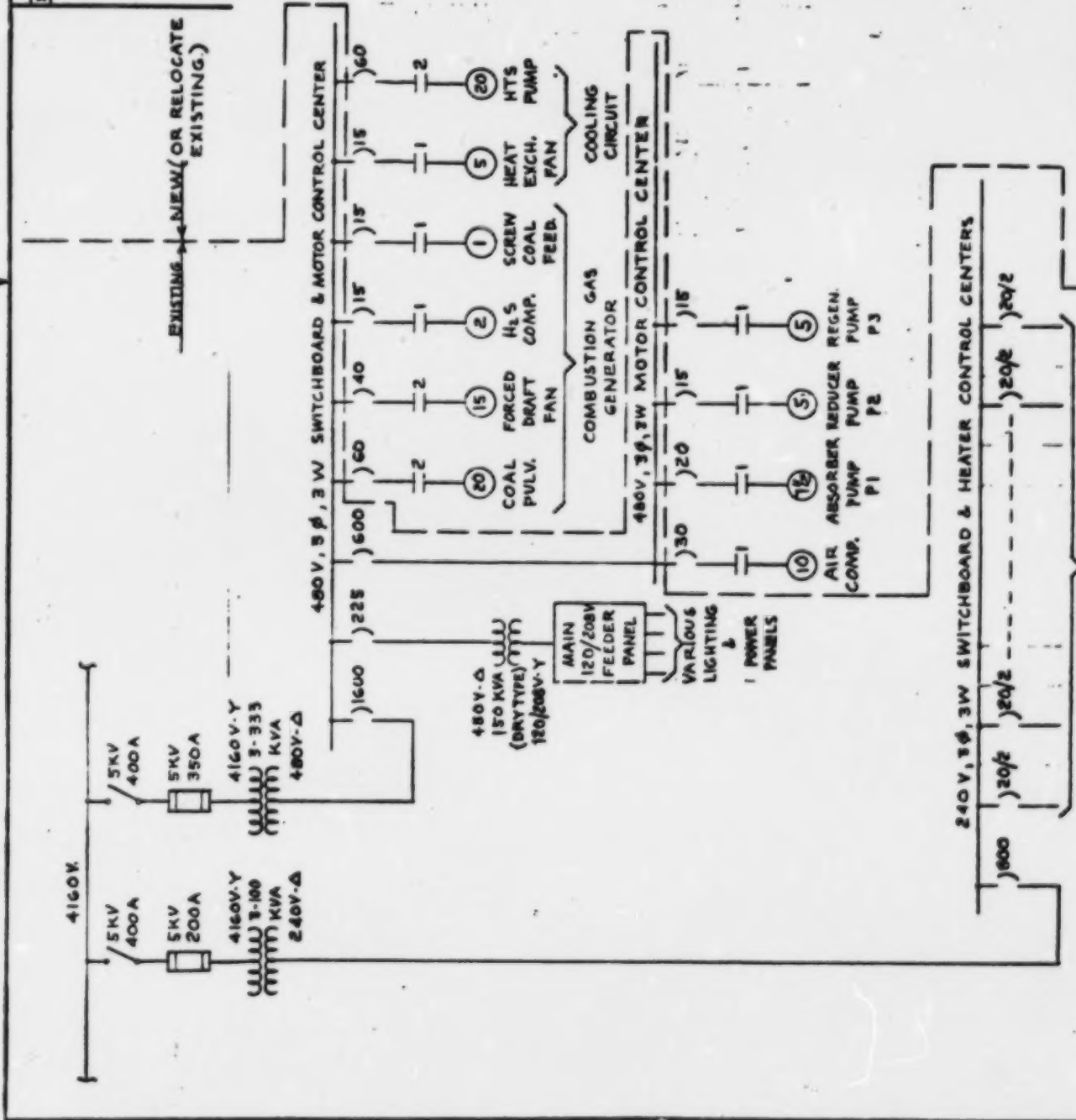
It is necessary to preheat all salt-containing components to above the melting point of the salt (about 750°F), to prevent plugging. Heat is supplied by resistance heaters located around the equipment. The preheat temperature is regulated by an ON-OFF controller with a manual set point. Thermocouples are attached to the equipment to indicate the overall preheat temperatures and to indicate when the desired preheat temperature is attained. The time to preheat will vary from 12 to 24 hours depending upon the mass being heated and the number of incremental preheat temperatures used. The desired preheat temperature is 800°F.

o. Electrical

An electrical system (Figure 2) is provided for operation of all of the electrically-powered process equipment. Maximum use is made of the Sodium Reactor Experiment facility distribution switch-gear and transformers.

Incoming 4160 volt power to the facility is stepped down by two separate existing substation transformer banks. One bank, consisting of 3-100 KVA, 4160 volt to 240 volt transformer connected 3-phase, delta, provides up to 350 kw of power for preheating of process pipes and small equipment. This power is distributed through existing heater control centers consisting of several panels of manually operable circuit breakers to which heater circuits are directly connected.

| REVISIONS |             |          |
|-----------|-------------|----------|
| REV       | DESCRIPTION | DATE     |
| 1         | 5/22/57     | APPROVED |



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Page 15

|                                                                                                                        |                                                    |
|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|
| <b>ATOMICS INTERNATIONAL</b><br>A DIVISION OF NORTH AMERICAN AVIATION, INC.<br>5000 BERRY AVENUE, CARROSA PARK, CALIF. |                                                    |
| SMALL PILOT PLANT - SO <sub>2</sub> REMOVAL<br>ELECTRICAL SINGLE LINE DIAGRAM                                          |                                                    |
| DRAWN: NEW JOHNSON<br>CHECKED: NEW JOHNSON<br>APPROVED: NEW JOHNSON                                                    | DATE: 5/22/57<br>SHEET NO.: 15<br>TOTAL SHEETS: 15 |

Figure 2



The second transformer bank consists of 3-333KVA, 4160 volt to 480 volt transformer connected 3-phase delta, providing power for all of the process equipment drive motors, heat for process tanks and vessels, and, by means of further transformation, power for plant lights, receptacles, instrumentation and miscellaneous low voltage equipment.

The 480 volt power is distributed through existing switch-gear and motor control centers. The motor control centers consist of combination circuit breaker-starter units, many of which are existing, though considerable rearrangement and replacement is necessary.

The 480 volt power for process tanks and vessels is distributed through existing heater control centers consisting of combination circuit breakers and electrically-operated contactors.

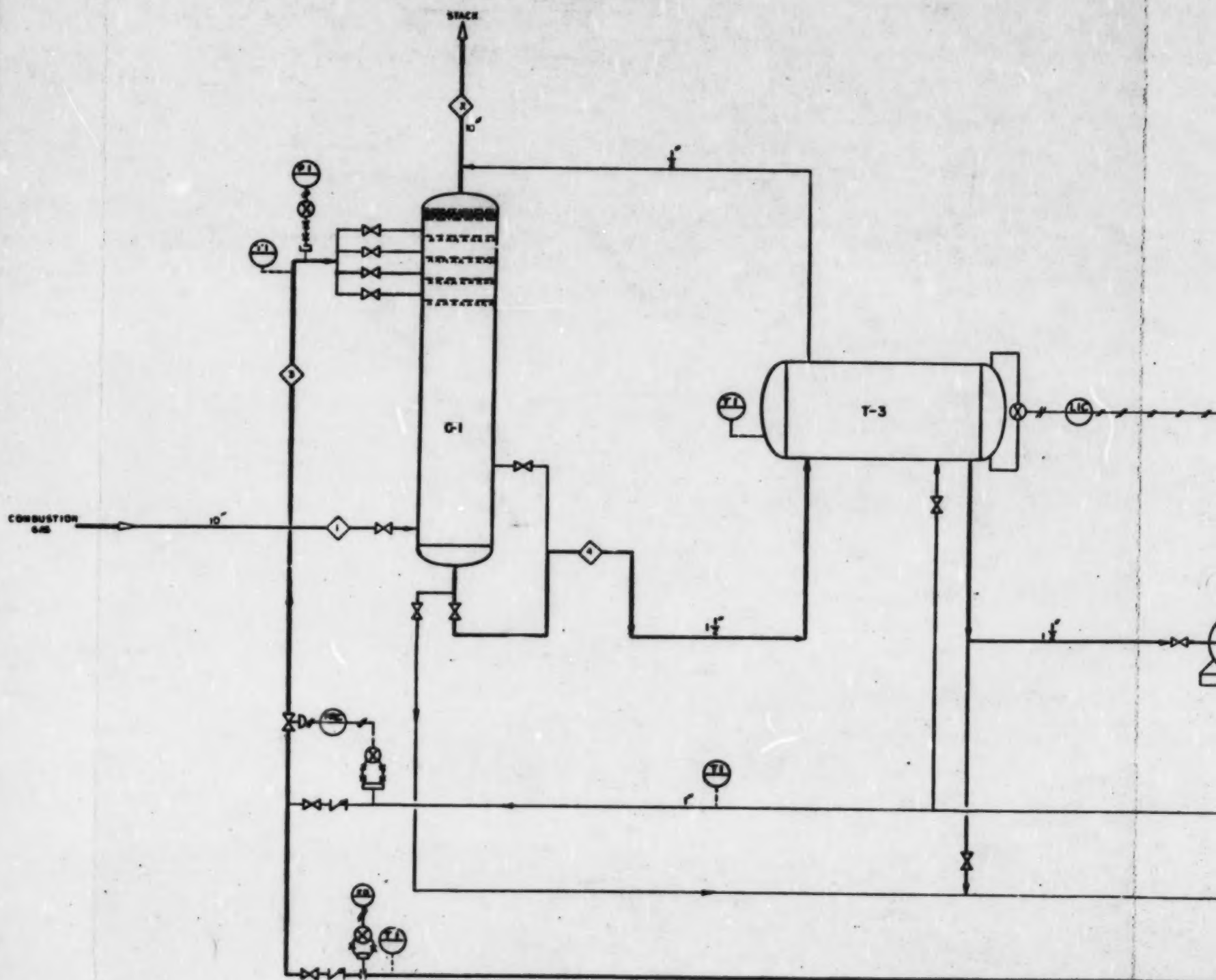
Plant lighting, receptables, instrumentation and other low voltage loads are supplied by an existing 150 KVA, 480 volt to 120/208 volt, 3-phase, wye, dry type transformer and various existing distribution circuit breaker panels.

2. Alternate Case - Agitated Vessels for the Reducer and Regenerator

Figure 3 is a flow diagram of this system which is identical with the previous design except that the sieve tray column reactors are replaced by three agitated vessels for both the reduction and regeneration steps. The reducer vessels, fabricated from Hastelloy G, are 4 ft in diameter by 15 ft high and contain mixers for agitating the process stream. Provision is made to operate the three agitated vessels independently or in series. The regenerator vessels are 2.5 ft in diameter by 10 ft high, fabricated from type 347

15

14



ABSORBER COLUMN  
C-1  
20" DIA X 20'

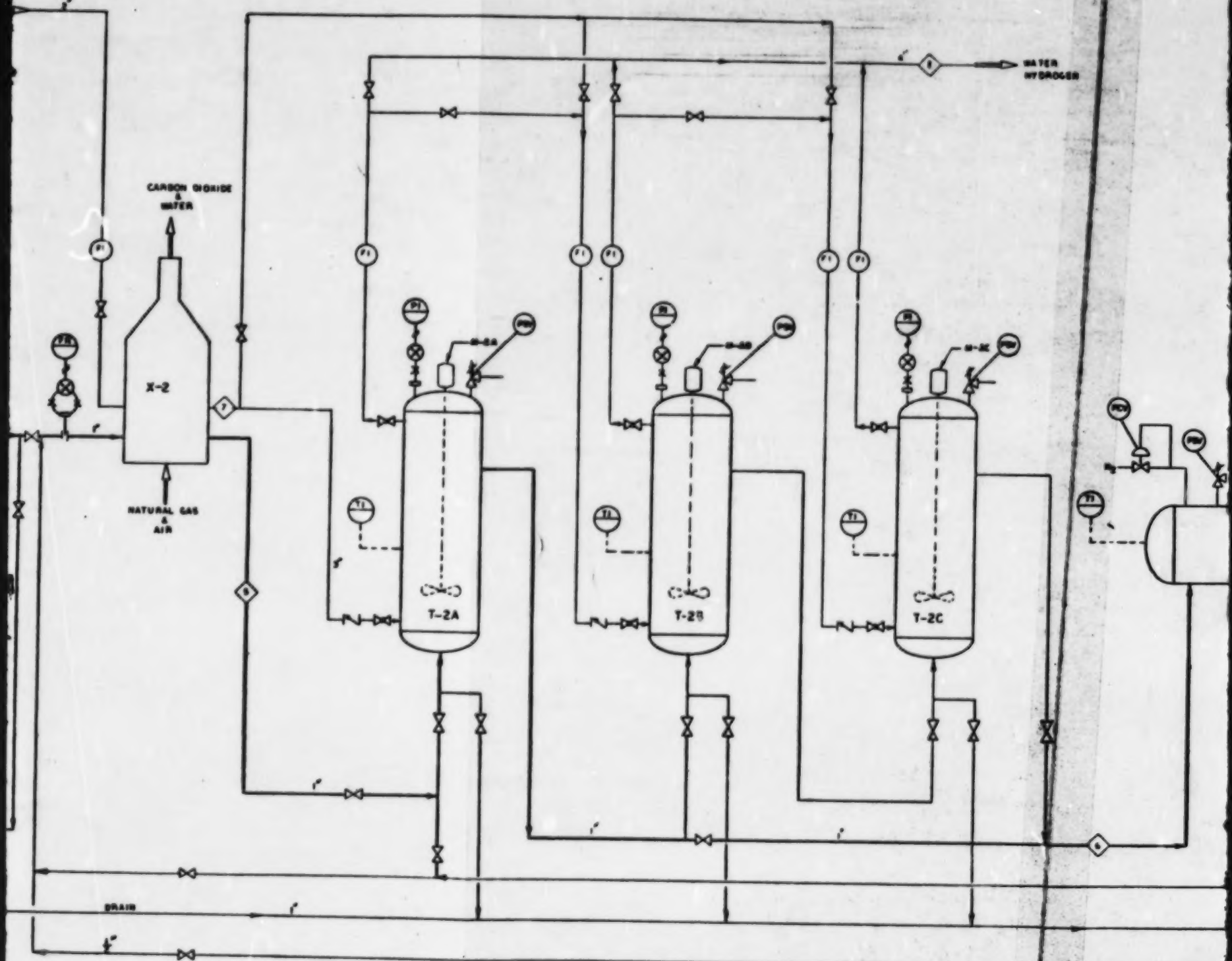
ABSORBER HOLDUP TANK  
T-3  
3'-6" DIA X 6'

ABSORBER  
CAPACITANCE  
HEAD  
HP

15

14





**HEATER**  
X-2

OUTY: CARBONATE 950,000 BTU/HR  
HYDROGEN 500,000 BTU/HR

**MECHANICAL MIXER**

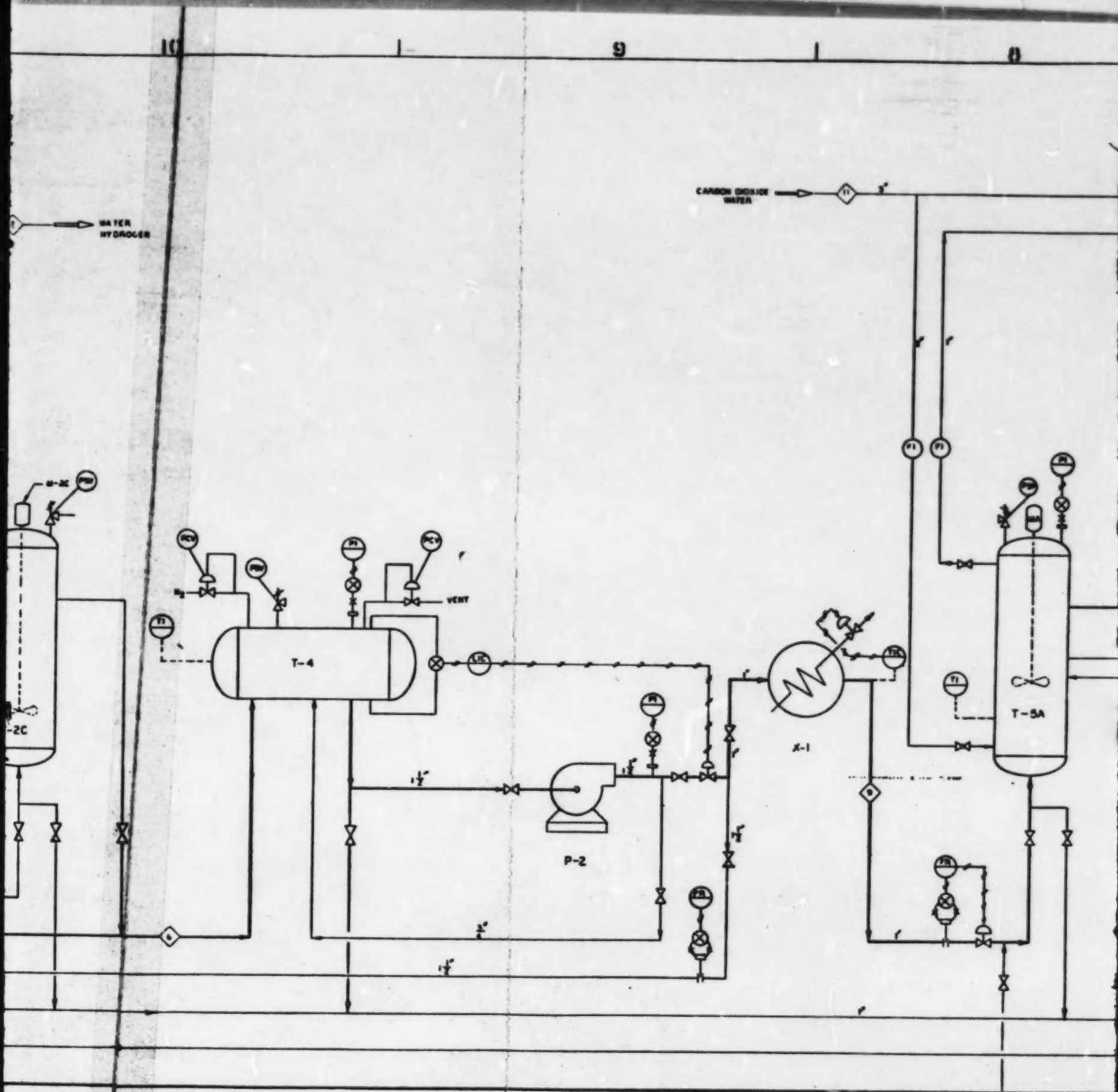
M-2A, M-2B & M-2C  
HP: 15

**REDUCER TANKS**

T-2A, T-2B & T-2C  
4' DIA X 15'

**REDUCER HOLD**

T-4  
6' DIA X 10'



**REDUCER HOLDUP TANK**  
 T-4  
 6" DIA X 10'

**REDUCER PUMP**  
 P-2  
 CAPACITY 20 GPM  
 HEAD 90 PSI  
 HP 5

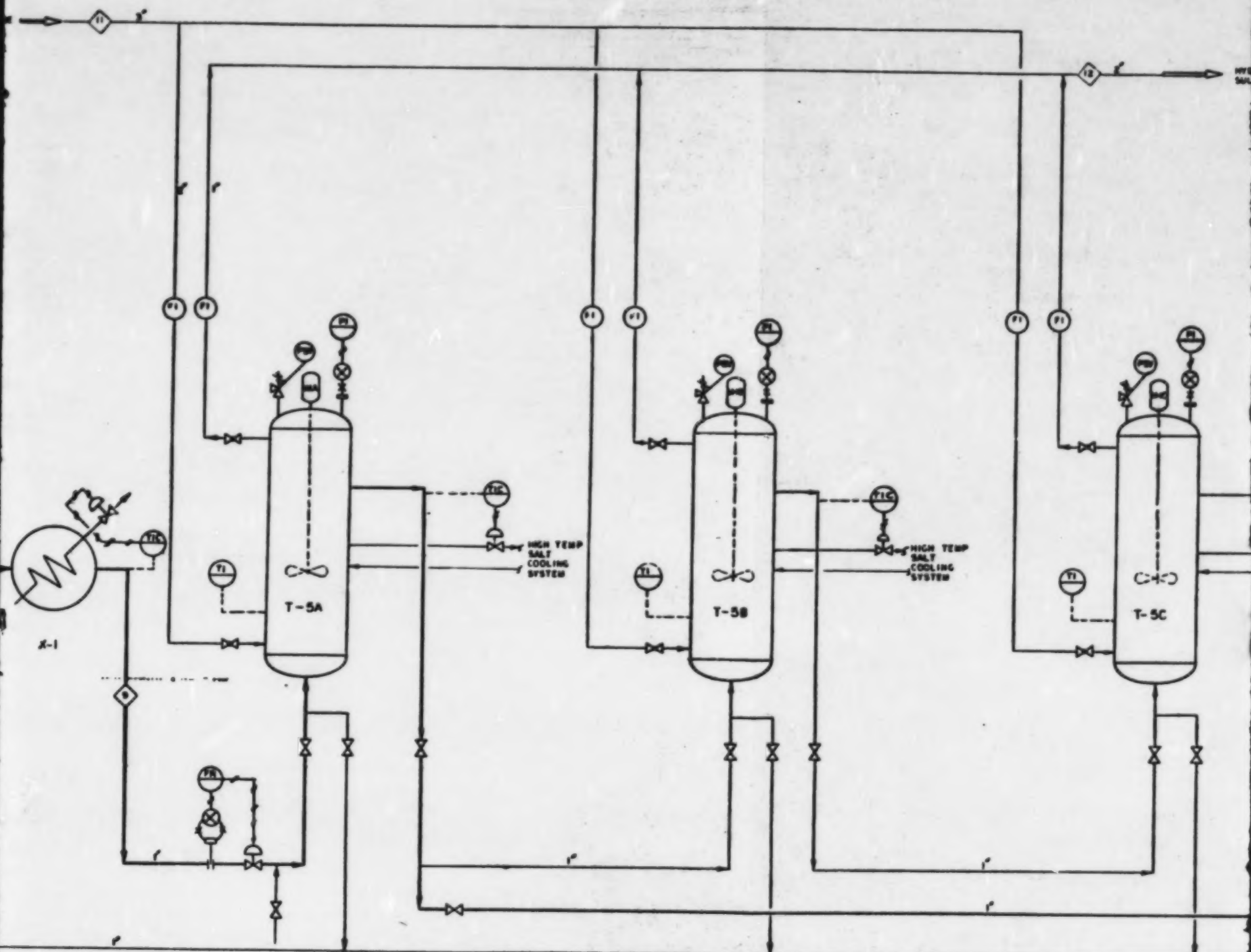
**REGENERATOR COOLER**  
 X-1  
 DUTY 750,000 BTU/Hr

**MECHANICAL MIXER**  
 M-1A, M-1B & M-1C  
 HP: 7.5

6

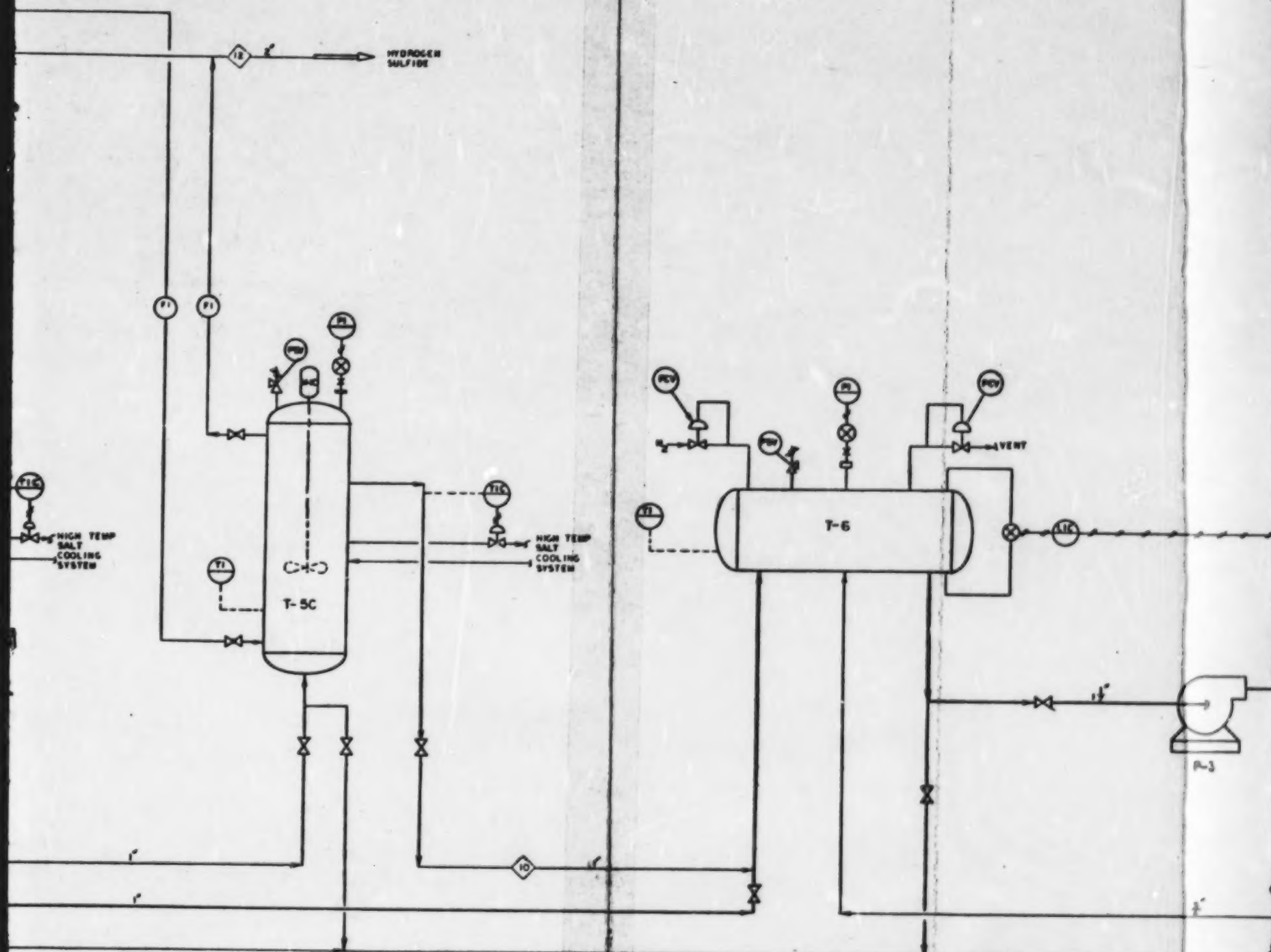
7

8

**REGENERATOR COOLER**X-1  
DUTY 750,000 BTU/Hr**MECHANICAL MIXERS**M-1A, M-1B & M-1C  
HP: 7.5**REGENERATOR TANKS**T-5A, T-5B & T-5C  
2'-6" DIA X 10'

9

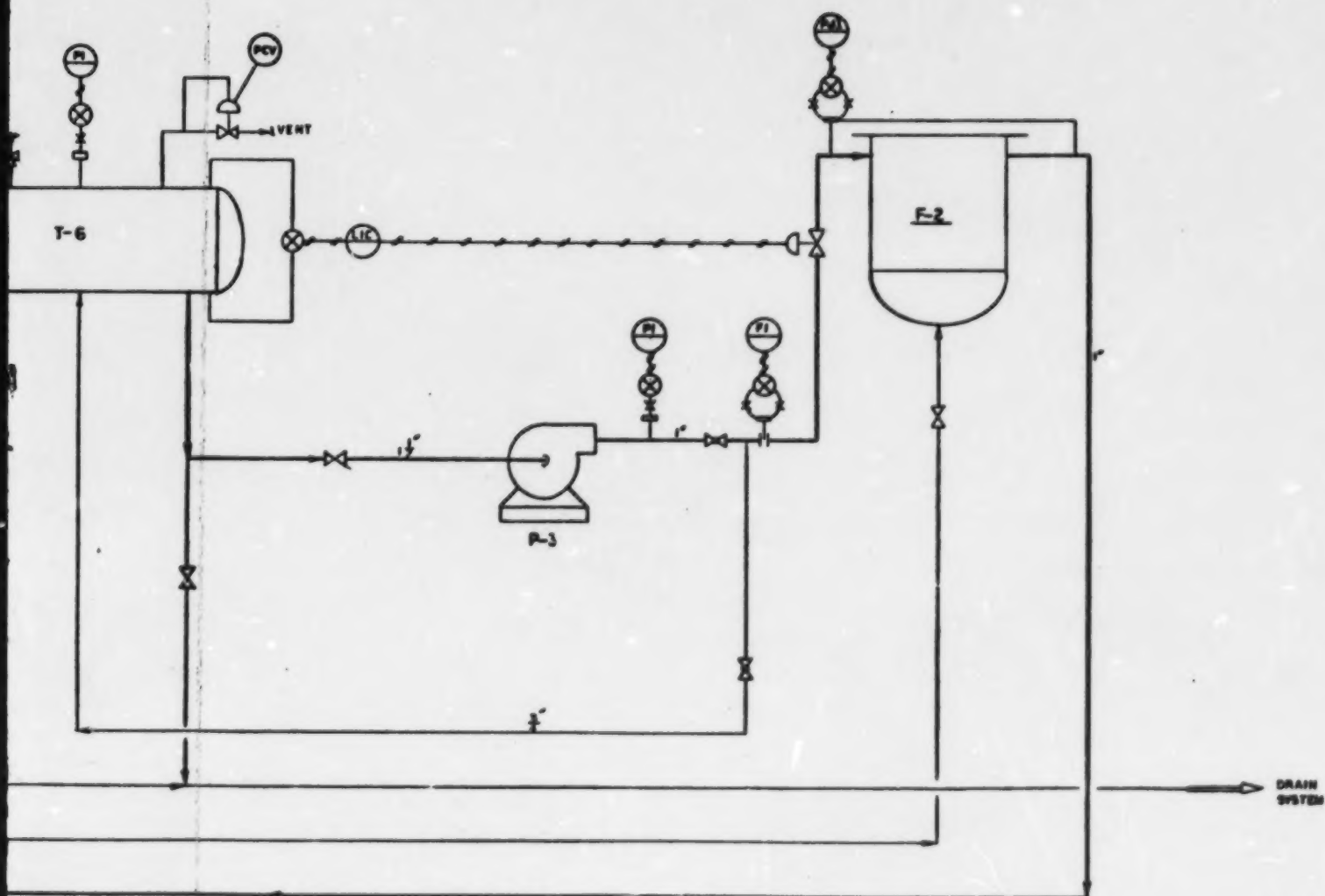
8



REGENERATOR HOLDUP TANK  
T-6  
5' DIA X 6'

REGENERATOR PUMP  
P-3  
CAPACITY 5 GPM  
HEAD 65 PSI  
HP 3

5



REGENERATOR HOLDUP TANK

REGENERATOR PUMP  
P-3  
CAPACITY 5 GPM  
HEAD 65 PSI  
HP 5

CATALYST FILTER  
F-2  
RATING: 2 MICRONS





stainless steel, and also contain mixers for agitating the process stream.

Figure 4 is an electrical single line diagram for the alternate case.

#### B. COMPONENT TEST LOOP

This section presents a system description of the Component Test Loop based upon the conceptual design effort. The primary function of this system is to test mechanical components of a size comparable to those anticipated for a molten carbonate plant integrated into a 60-160 Mwe coal-fired unit. Components to be tested include pumps, valves, flow measurement devices, heat exchangers, fly ash removal devices and process instrumentation.

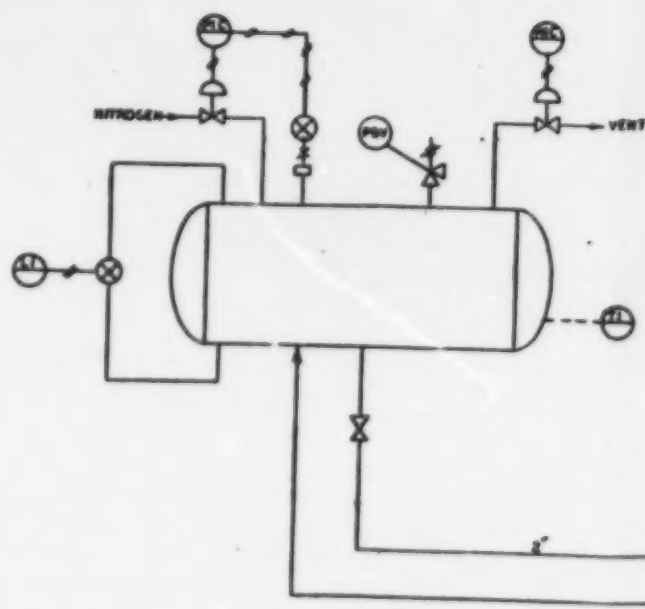
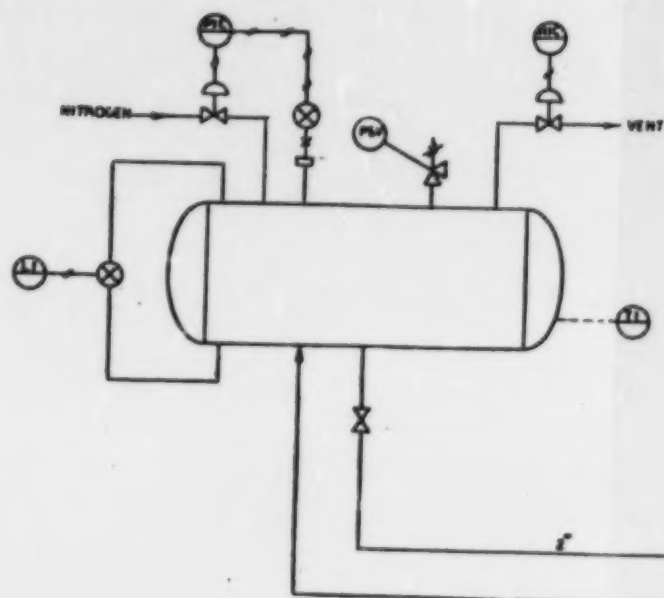
Figure 5 is a P&I diagram of the proposed system. The system consists of two circulating systems with only two common pieces of equipment, a salt-to-salt heat exchanger and a gas fired in-line heater. (If an electrical heater is used in the Large Pilot Plant, an electrical heater would replace the gas fired heater). As designed, the system will be capable of simultaneous testing of components at 1150 and 850°F. Because the two circuits are independent, the salt composition in each loop can be adjusted to simulate the process stream of interest. The specific sizes and quantities referred to in Figure 5 are preliminary and will be re-evaluated during final design.

Each main circulation system consists of a test pump, a calibrated flow measurement device, a flow throttling valve, and means of introducing or removing heat. In addition, connections are provided for installing test valves, flow metering devices, materials test specimens and particulate (fly ash and catalyst) removal devices in the circulating loops, for performance and reliability testing. (The location of these is shown schematically in Figure 5, details will evolve during final design).



SULFIDE LOOP STORAGE TANK  
T-2  
3' DIA X 6'

REDUCER PUMP  
P-2  
CAPACITY: 25 GPM  
HEAD: 100 PSI  
NPS: 10



SULFATE LOOP STORAGE TANK  
T-1  
3' DIA X 6'

ABSORBER PUMP  
P-1  
CAPACITY: 20 GPM  
HEAD: 150 PSI  
NPS: 10

A

10

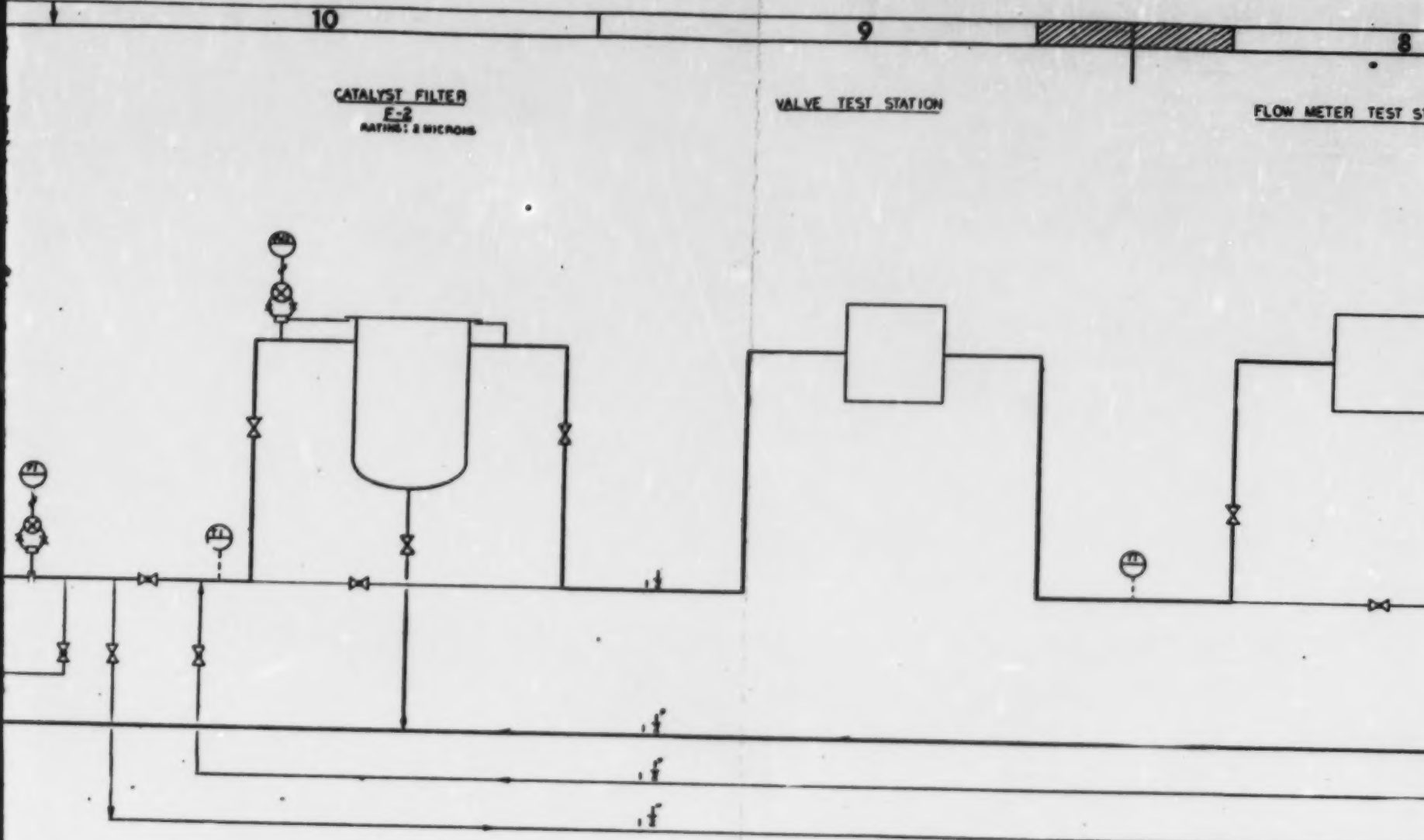
CATALYST FILTER  
F-2  
RATING: 2 MICRONS

9

VALVE TEST STATION

8

FLOW METER TEST STATION

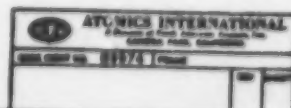
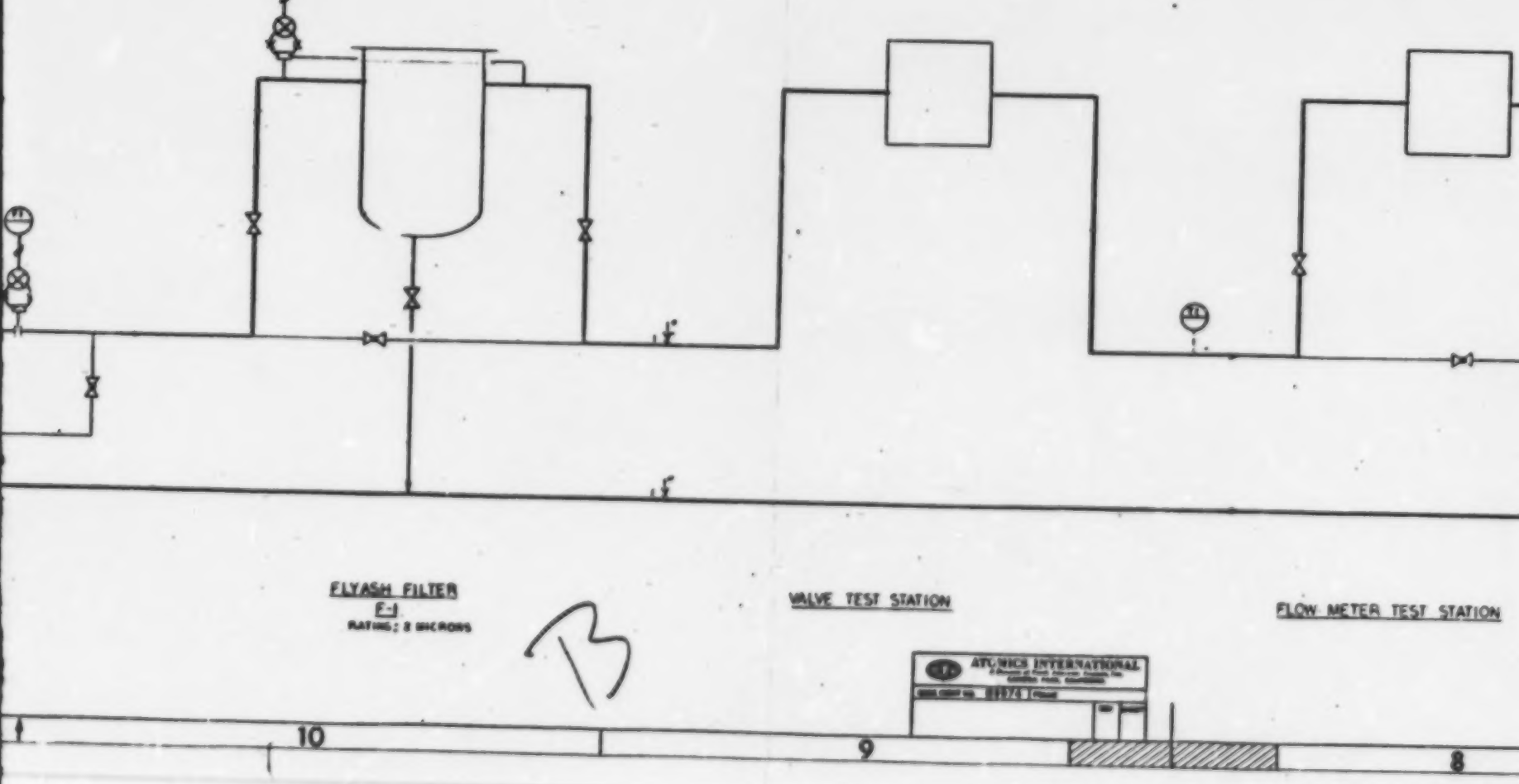


FLYASH FILTER  
F-1  
RATING: 2 MICRONS

VALVE TEST STATION

FLOW METER TEST STATION

13



8

FLOW METER TEST STATION

7

HEATER  
X-3A & 3B  
DUTY "A":  $3 \times 10^6$  BTU/Hr  
DUTY "B":  $5 \times 10^6$  BTU/Hr

COMBUSTION GAS

X-3A  
X-3B

NATURAL GAS  
AIR

8

FLOW METER TEST STATION

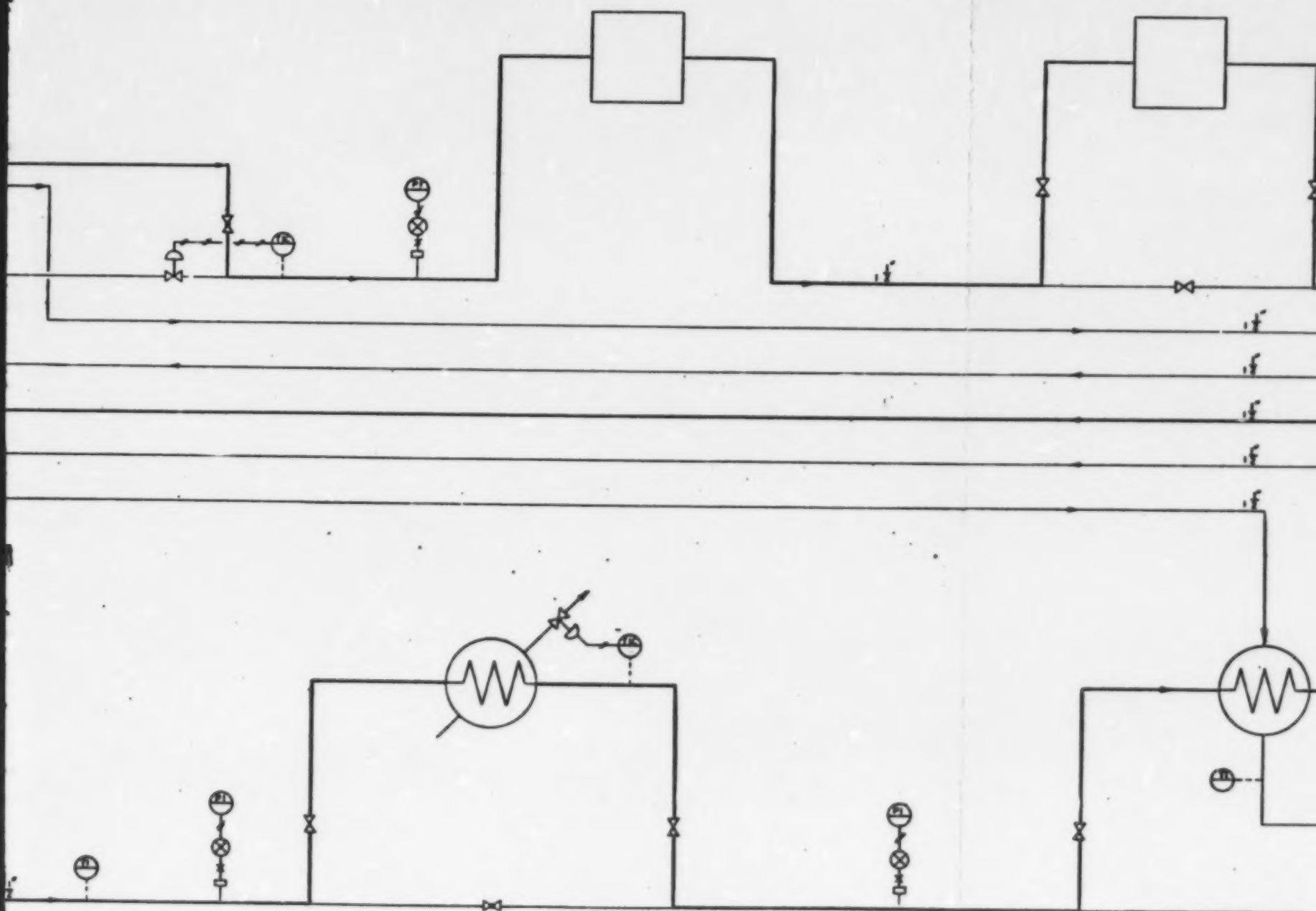
7

MATERIALS STUDY STATION

1000  
TU/HR  
TU/HR

VALVE TEST STATION

FLOW METER TEST STATION



TRIM COOLER  
X-1  
DUTY:  $2 \times 10^6$  BTU/HR

ECONOMIZER  
X-2  
DUTY:  $3 \times 10^6$  BTU/HR



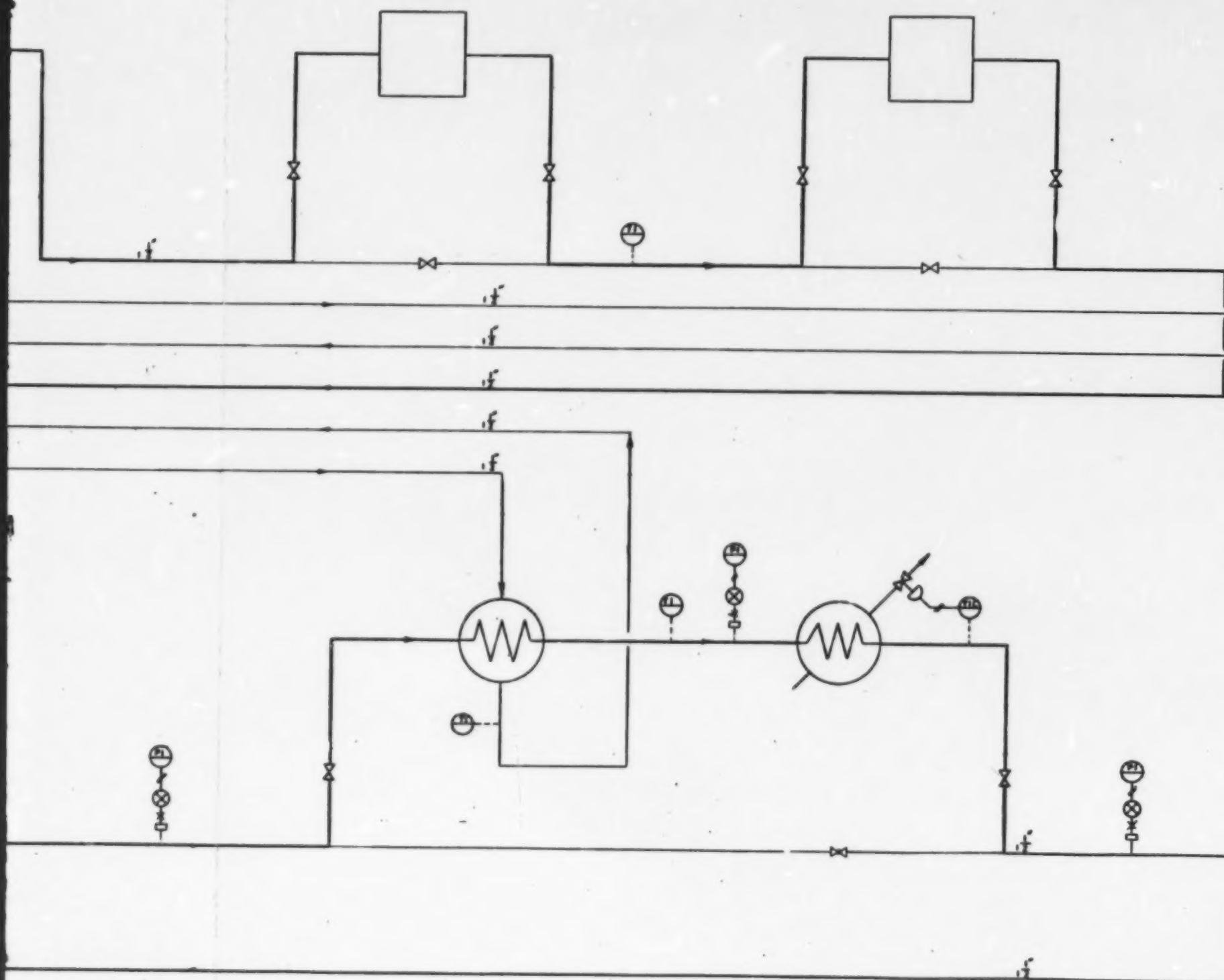
5

4

3

FLOW METER TEST STATION

MATERIALS STUDY STATION



ECONOMIZER

X-2  
DUTY:  $3 \times 10^6$  BTU/HR

COOLER

X-4  
DUTY:  $2.8 \times 10^6$  BTU/HR

5

4

3

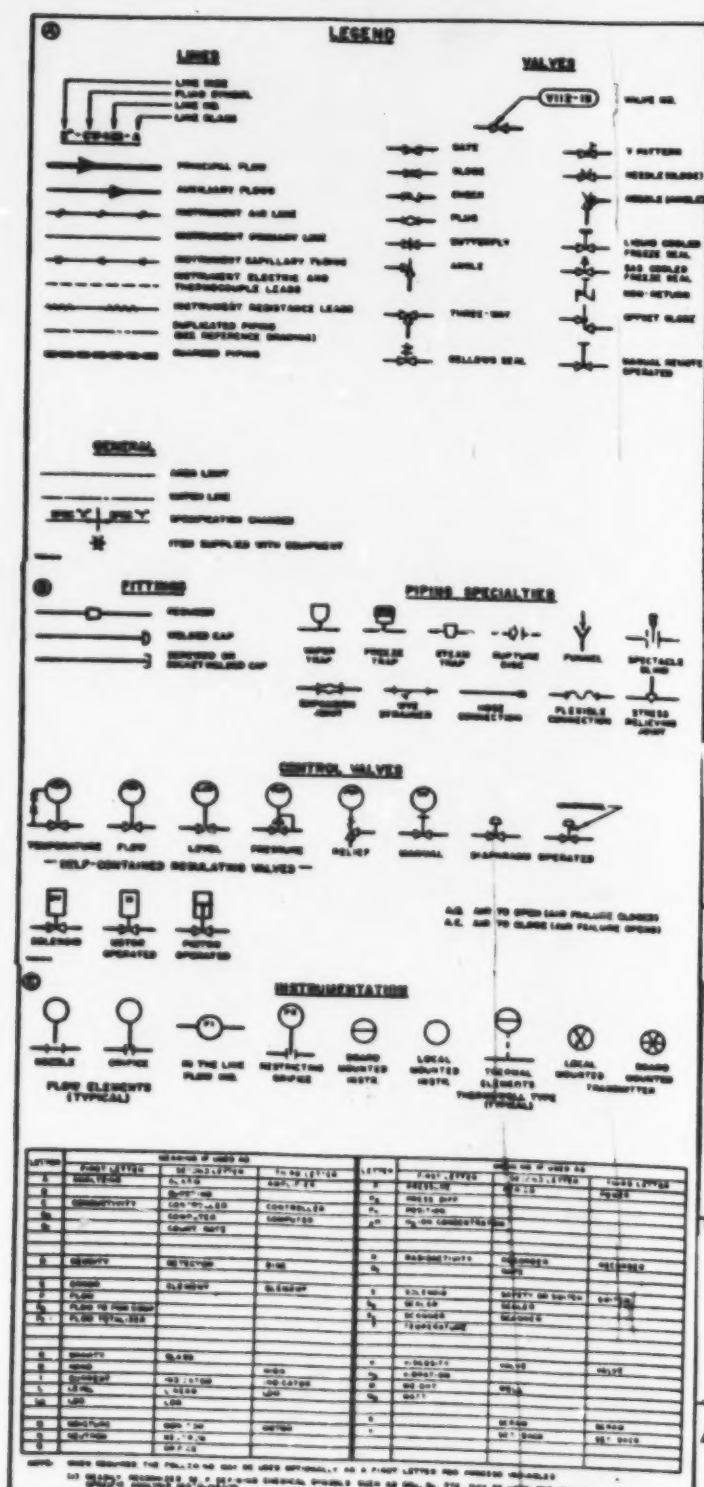
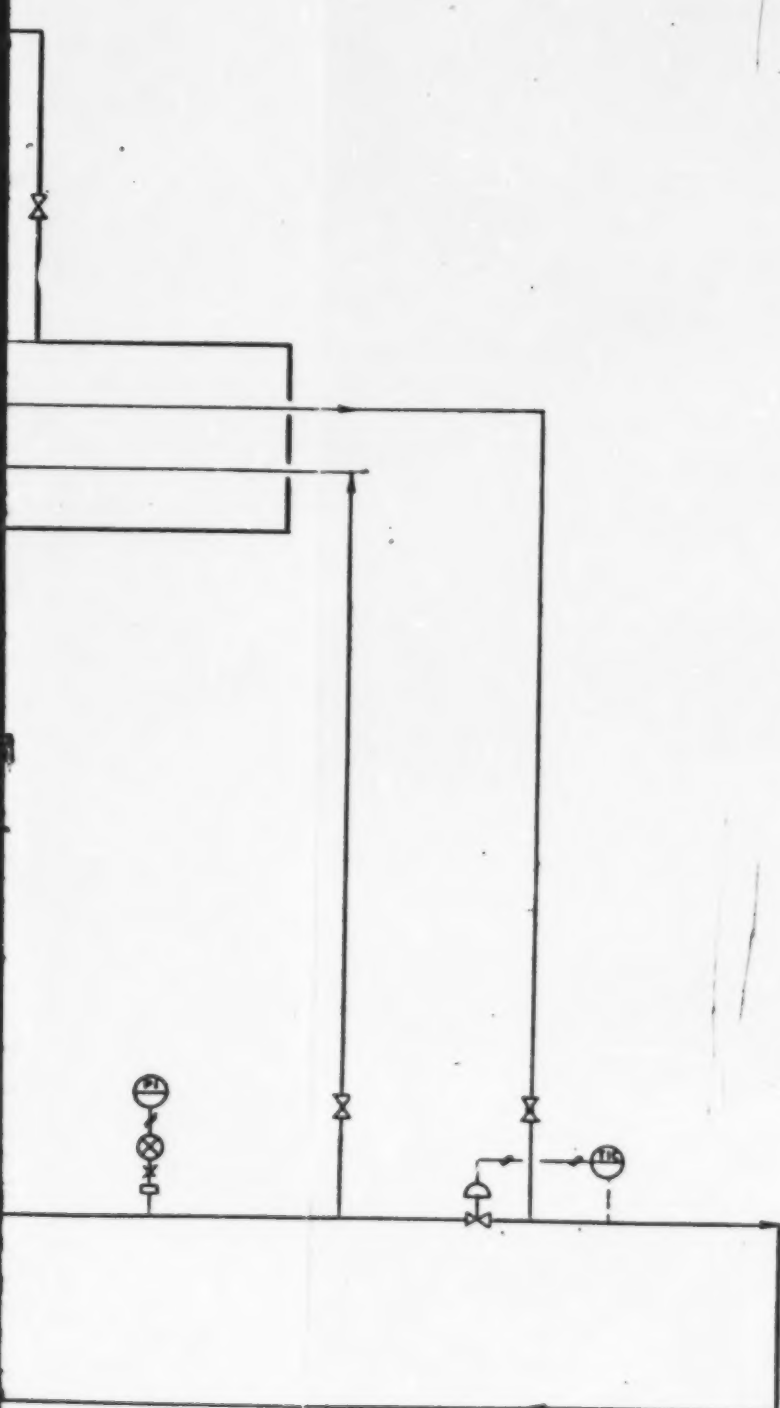


Figure 5



The flow of the process stream passes from the pump, through the throttling valve and calibrated flow meter, through the particulate removal devices, to the heat transfer section and back to the pump. A tank is connected to the pump section to accommodate fluid expansions and contractions due to temperature changes. This tank is also utilized to pressurize the system and to store the process fluid when the system is not in operation.

Provisions will be made to preheat the circulating loops prior to filling the system with molten salt.

#### 1. Sulfide Loop

The fluid circulating through this loop will usually be molten carbonate containing sulfides and dissolved iron. The sulfide loop consists of a circulation pump, a surge tank, filter, heat exchangers, test stations and interconnecting piping.

The equipment in the loop is arranged to permit one section to operate at up to 1150°F and the other section to operate simultaneously as low as 850°F. Fluid at temperatures up to 1150°F is pumped around the loop by a vertical free-surface pump. The pump will have the hydraulic characteristics of a pump to be used in the prototype plant. The fluid passes through an economizer to reject heat and reduce the temperature to 850°F. If isothermal loop operation is desired, flow can bypass the economizer. Fluid leaves the economizer and flows through a filter, valve test station and a flow meter test station before going to a gas-fired heater. Heat is absorbed and the fluid temperature increased to 1150°F. Fluid at this temperature passes through a valve test station, a flow meter test station and a materials test station before returning to the pump.



## 2. Sulfate Loop

The fluid circulating through this loop will be molten carbonate containing sulfates, sulfites, and fly ash. The sulfate loop consists of a circulation pump, a surge tank, filter, heat exchangers, test sections, and interconnecting piping.

The pump, filter and test stations operate at the same temperature, 850°F. Fluid at this temperature passes through the pump, and on to a filter, valve test station, flow meter test station and a materials test station. The fluid then passes through three heat exchangers arranged in series where heat is absorbed from the sulfide loop and rejected to an auxiliary cooling circuit. If no heat is absorbed from the sulfide loop and a heat input is required, the fluid flows to a gas-fired heater. The fluid leaving the gas-fired heater or the last heat exchanger is controlled to the desired temperature and is returned to the pump. The pump will have the hydraulic characteristics of a pump to be used in the prototype plant. The pump circulates fluid at 850°F through the test sections and filter. The fluid temperature then varies between 840 and 1130°F as it passes through the four heat exchangers. A trim cooler establishes the desired temperature differences in the second exchanger. The next heat exchanger is an economizer type of unit that duplicates the economizer to be used in the prototype plant. Heat is transferred through the economizer to the sulfate loop from the 1150°F sulfide loop. The sulfate loop temperature increases from 830°F to 1130°F. The cooler removes the heat input from the economizer and controls the loop temperature to 850°F. A heating coil is installed in the gas-fired heater of the sulfide loop to enable the temperature to be controlled at 850°F by adding heat if necessary.



### 3. Test Stations

Test stations will be installed in the component test loop to provide the capability of testing materials, flow meters and valves. Two sets of test stations are provided in the sulfide loop. The test stations see the same fluid and have the same mass flow rate. The fluid temperature in each station may be controlled at different levels. This is to enable direct comparisons to be made.

A similar series of test stations will be installed in the sulfate loop. These test stations will operate isothermally but at the desired (and controlled) temperatures.

### 4. Auxiliary Systems

An auxiliary cooling circuit is provided to remove the heat from the sulfate system in order to control its temperature. The fluid circulating through the circuit is the same high temperature heat transfer salt used to provide cooling in the small pilot plant.

System preheat is from resistance heaters surrounding the equipment. The temperature is regulated by ON-OFF controllers and the temperature is measured by thermocouples attached to the pipes.

Instrumentation is provided to monitor loop operation and to evaluate individual components performance. Special test instruments for detailed data gathering are not shown. Temperature, pressure and flow are measured throughout the system to enable energy balances to be made. Instrument types are those of the SPP.

The electric power is supplied from the distribution switchgear located at the Sodium Reactor Experiment. The motor, preheating, and lighting



are integrated into the distribution systems for the two designs of the SPP, and are shown in Figures 6 and 7.

Nitrogen is supplied by cylinders of nitrogen that are also the SPP supply. Instrument air is supplied by the air compressor used by the SPP.

#### IV. PLANT ARRANGEMENT

##### A. SMALL PILOT PLANT

The process portion of the small pilot plant will be located in the high-bay area of the Sodium Reactor Experiment facility located at the Santa Susana field laboratory. If a coal furnace is installed, it would be located external to the building and the flue gases ducted into the absorber. The loop must drain by gravity into one of three holdup tanks located on the high bay floor; therefore, all components except the holdup tanks and the associated pumps are hung from a structural steel frame. The proposed arrangement is shown in Figures 8 and 9.

The small pilot plant is a high temperature, low pressure system, with a design pressure of 150 psi. The absorption and regeneration steps have a design temperature of 900°F. The reduction step has a design temperature of 1200°F. The design temperatures are 50-100°F higher than the anticipated operating temperatures. The high temperatures require expansion loops to avoid high stresses in piping and nozzles. Space is allowed to facilitate removal and replacement of components for test purposes. Insulation will be applied to reduce the heat loss and to protect personnel.

Piping and equipment will be fabricated of type 347 stainless steel and Hastelloy G, stainless steel is used when the system is designed for 900°F; Hastelloy G is used for equipment designed for 1200°F. The loop vessels and





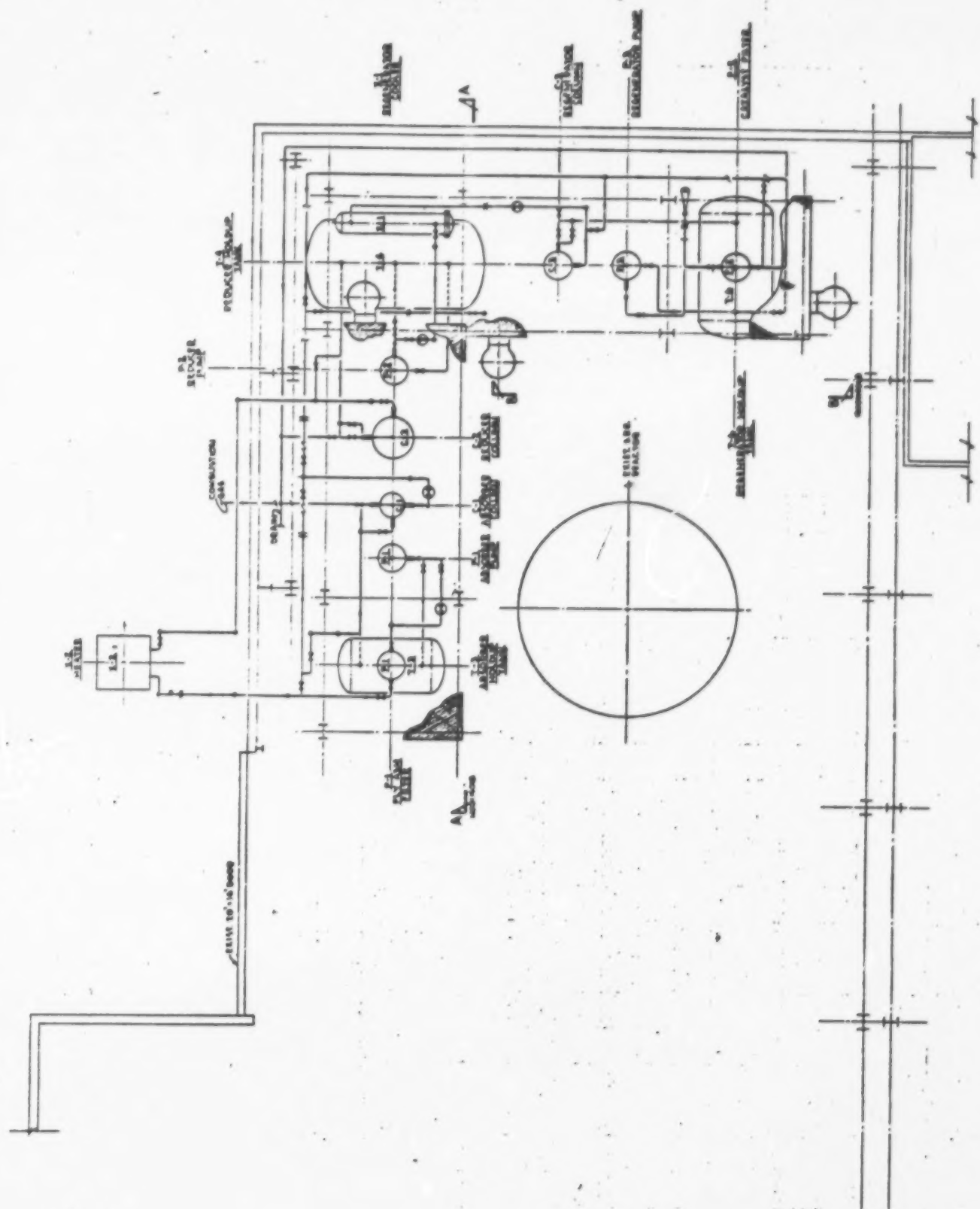


Figure 8

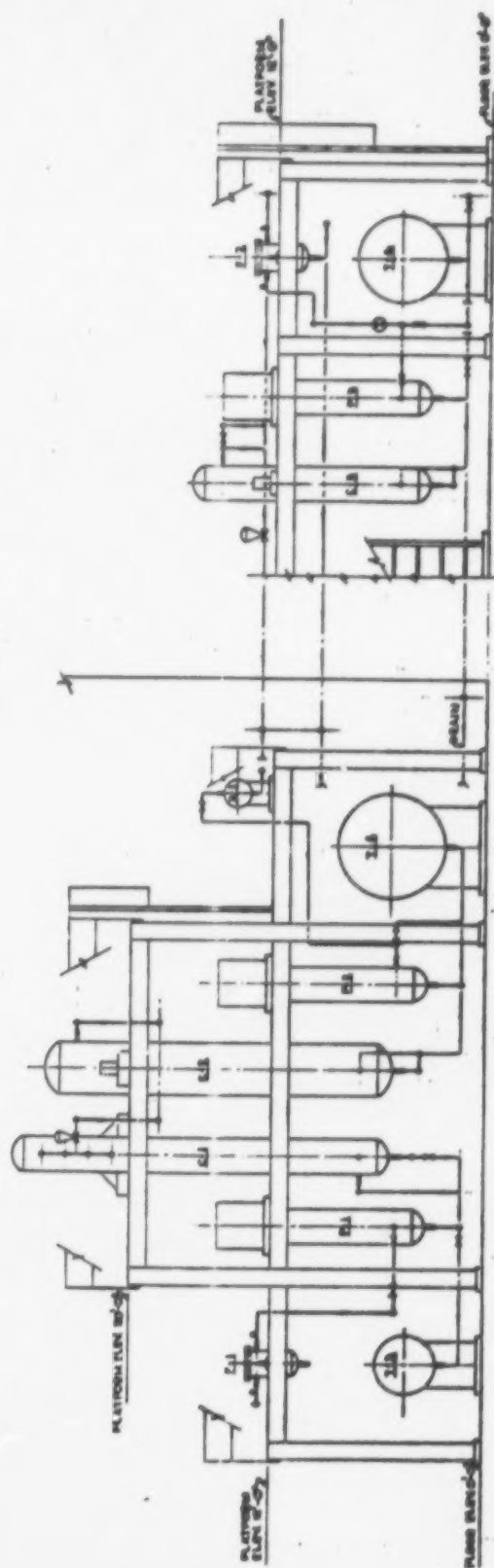


Figure 9



piping will be designed to ASME and ASA standards and codes.

B. COMPONENT TEST LOOP

The component test loop will also be located in the high-bay area of the Sodium Reactor Experiment located at the Santa Susana field laboratory. The equipment will be supported from the same structural steel in the same manner that the equipment used in the small pilot plant will be supported. The equipment arrangement is shown in Figure 10.

The piping equipment will be fabricated of type 347 stainless steel where the design temperature is 900°F. Hastelloy G will be used when the design temperature is 1200°F. The loop vessels and piping will be designed to ASME and ASA standards and codes. Insulation will be applied to reduce the heat loss and to protect personnel.

V. COST ANALYSIS OF FACILITY

Tables 2, 3 and 4 list the cost breakdown of each of the laboratory systems. The cost estimate is based upon the conceptual design, and covers only the engineering and construction of the two systems. It does not include costs of special test instrumentation or operation of the testing program. In addition, since the installation is scheduled for the SRE facility, no new electrical facilities such as high voltage substations, transformers, lighting, convenience outlets, grounding, PA system, etc., have been included.

Also, no provisions have been made in the estimates for any of the following:

- a. Building modification
- b. insurance during construction
- c. office, furniture, laboratory equipment, etc.



Figure 10

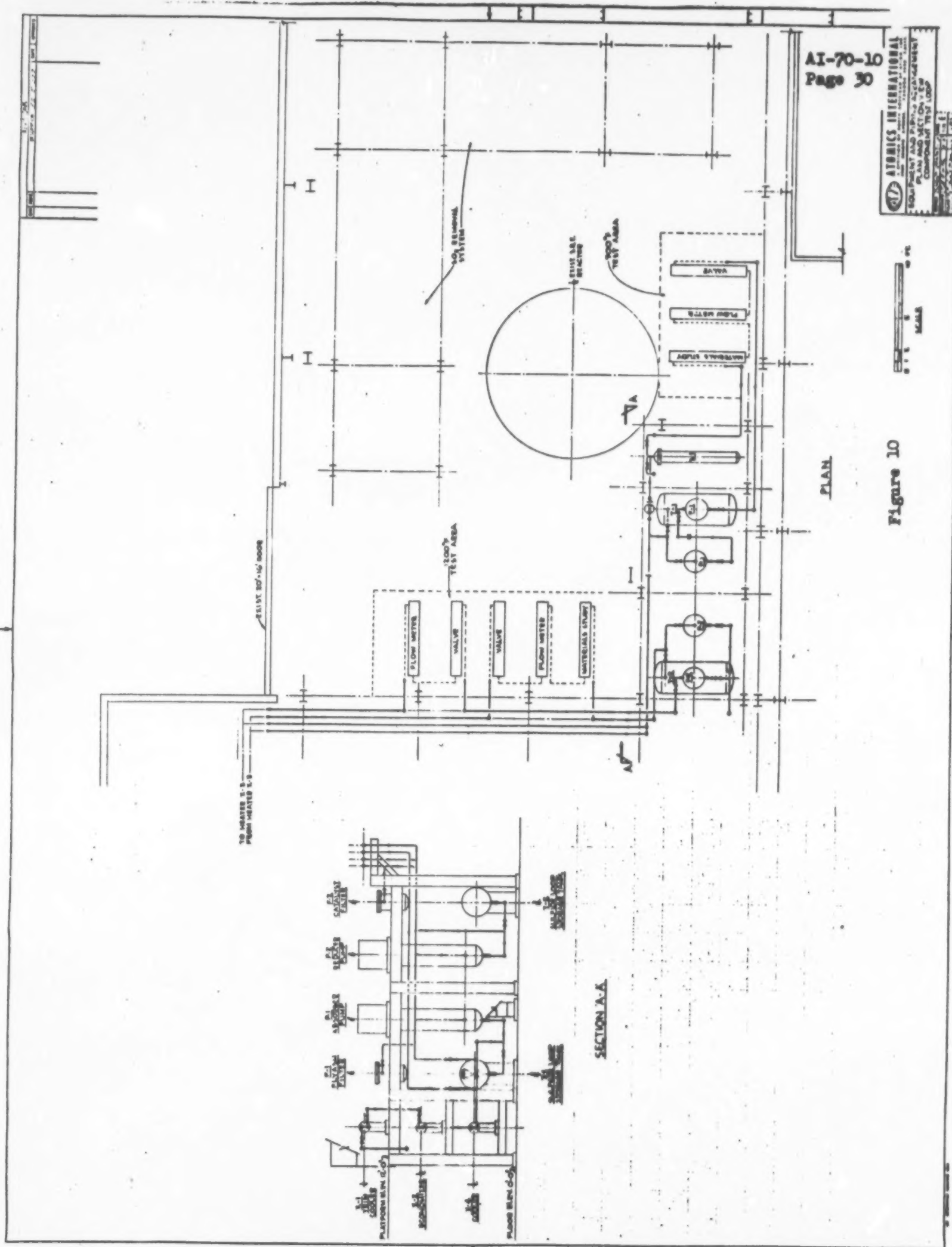




TABLE 2

Cost Estimate - Small Pilot Plant - Sieve Tray Column Design

|                                                                                | Item Cost | Total Cost  |
|--------------------------------------------------------------------------------|-----------|-------------|
| A. Engineering Design                                                          | \$        | \$ 110,000  |
| B. Equipment (includes installation)                                           |           | 1,136,925   |
| 1. Flue Gas Generation System<br>(coal burner, precipitator,<br>ducting, etc.) | 355,200   |             |
| 2. Reaction Vessels                                                            | 60,050    |             |
| 3. Tanks                                                                       | 61,350    |             |
| 4. Pumps                                                                       | 23,750    |             |
| 5. Filters                                                                     | 11,000    |             |
| 6. Heat Exchange Equipment                                                     | 52,900    |             |
| 7. Piping                                                                      | 173,825   |             |
| 8. Valves                                                                      | 112,900   |             |
| 9. Instrumentation                                                             | 163,150   |             |
| 10. Electrical                                                                 | 57,000    |             |
| 11. Structural                                                                 | 22,000    |             |
| 12. Insulation                                                                 | 43,800    |             |
| C. Contractors Overhead and Profit<br>(25% of equipment cost)                  |           | 284,230     |
| D. Contingency<br>(20% of B and C)                                             |           | 284,845     |
| TOTAL COST                                                                     |           | \$1,816,000 |



TABLE 3

Cost Estimate - SPP - Agitated Vessel Design

|                                                                 | <u>Total Cost</u> |
|-----------------------------------------------------------------|-------------------|
| A. Engineering Design                                           | \$ 110,000        |
| B. Equipment (includes installation)                            | 1,305,050         |
| C. Contractor's Overhead and Profits<br>(25% of equipment cost) | 326,300           |
| D. Contingency                                                  | <u>326,650</u>    |
| TOTAL COST                                                      | \$2,068,000       |



TABLE 4

Cost Estimate - Component Test Loop

|                                                                | Item Cost | Total Cost  |
|----------------------------------------------------------------|-----------|-------------|
| A. Engineering Design                                          | \$        | \$ 90,000   |
| B. Equipment (includes installation)                           |           | 638,250     |
| 1. Tanks                                                       | 24,200    |             |
| 2. Pumps                                                       | 12,800    |             |
| 3. Filters                                                     | 15,000    |             |
| 4. Economizer                                                  | 61,000    |             |
| 5. Heat Exchange Equipment*                                    | 69,800    |             |
| 6. Piping                                                      | 109,900   |             |
| 7. Valves                                                      | 144,000   |             |
| 8. Instrumentation                                             | 142,150   |             |
| 9. Electrical                                                  | 37,400    |             |
| 10. Structural                                                 | 7,000     |             |
| 11. Insulation                                                 | 15,000    |             |
| C. Contractor's Overhead and Profit<br>(25% of equipment cost) |           | 159,550     |
| D. Contingency<br>(20% of B and C)                             |           | 159,200     |
| TOTAL COST                                                     |           | \$1,047,000 |

\* Includes gas-fired heater, during final design heaters for the two systems may be combined.



- d. PERT systems and progress reports
- e. overtime pay

## VI. BRIEF DESCRIPTION OF EXPERIMENTAL PROGRAM

### A. SMALL PILOT PLANT

The operation of the SPP will provide process operating experience, and will be utilized to evaluate the performance of the chemical reactors and to demonstrate the process on an integrated basis under realistic plant operating conditions. Secondary objectives will be investigate the effects of trace impurities on process chemistry, and of operational variations on plant performance. The results of these tests will be utilized to develop specifications and operating criteria for a demonstration plant. A list of the specific information desired is given below:

Absorber. The efficiency of sulfur dioxide removal will be measured, and compared with previous bench-scale data. Among the variables to be studied are: the liquid and gas flow rates, pressure drop, flue gas composition ( $O_2$ ,  $H_2O$ ,  $NO_x$ ,  $SO_3$ , etc.), fly ash content in the flue gas stream, nozzle performance, number and type of nozzles, and demister performance.

In-Line Heater. The thermal performance and the effect of operating time on performance will be determined.

Reducer. The efficiency of the reduction step will be studied and compared with bench scale data. Among the variables to be studied are: liquid and gas flow rates, type of contactor, degree of recycle (i.e., amount of entering sulfide), operating temperature and pressure, and amount of catalyst.

In-Line Cooler. The thermal performance and effect of operating time on performance will be determined.



Regenerator. The efficiency of the regeneration step will be studied and compared with bench scale data. Among the variables to be studied are: liquid and gas flow rates, type of contactor, recycle ratio, operating temperature and pressure, catalyst separation, and regeneration gas composition.

Pumps, Valves and Filters. Their performance will be studied and compared with data from the Component Test Loop.

B. COMPONENT TEST LOOP

The operation of the CTL will provide operating experience and will establish maintenance requirements. Any changes to component designs can be made prior to installing the components in the prototype plant. The components to be tested and the specific information desired are listed below:

Pumps. The hydraulic performance, including net positive suction head (NPSH) requirements, will be determined and compared to earlier data obtained by the vendor using water. Operation of the seals and hydraulic bearings will be observed. Of particular interest is the effect of fly ash on pump reliability. As an illustration of the type of tests to be conducted on the components, a proposed test plan for evaluating the pump performance is appended.\*

Economizer. The thermal performance and the effect of operating time on performance will be determined. The effect of thermal gradients will be observed.

Valves. The reliability of control valves with thermal cycling and solid impurities in the carbonate will be determined. Any galling and erosion of components will be noted.

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\* Not appended in this distribution.



Flow Measurement. The suitability of different flow meter systems including the flow element and dp cell will be determined. Erosion of the flow element and drift of the transmitter will be established.

Materials. Corrosion tests will be performed to determine the corrosion rate as a function of melt composition, temperature, velocity and stress. Particular attention will be paid to welded materials.